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VERIFICATION TECHNOLOGIES

Cooperative Aerial Surveillance in International Agreements

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CONGRESS OF THE UNITED STATES
OFFICE OF TECHNOLOGY ASSESSMENT

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Foreword

In the changing geopolitical environment of 1989, President George Bush revived and amplified President Dwight D. Eisenhower's 1955 "Open Skies" proposal calling for mutual aerial surveillance of NATO and Warsaw Pact territories. Meanwhile, Conventional Armed Forces in Europe Treaty negotiators were considering aerial inspections as one measure for monitoring arms reductions. Although neither of these applications of cooperative aerial surveillance have yet been agreed to, negotiations continue on both. Recently, nations without access to the kinds of national technical means of verification available to the United States and the Soviet Union have shown interest in reciprocal overflights as a means of building confidence among international neighbors.

This report examines the potential and limitations of cooperative aerial surveillance as a means of supporting the goals of a variety of international agreements. It surveys the types of aircraft and sensors that might be used. It reviews the status of and issues raised by the Open Skies Treaty negotiations as an extended example of an aerial surveillance regime. The report concludes with a quantitative analysis of one possible use of cooperative overflights: the search for potential arms control violations.

In 1989 the Senate Committee on Foreign Relations and House Committee on Foreign Affairs asked OTA to undertake an assessment centering on the technologies and techniques of monitoring the prospective START Treaty. In its request, the Committee on Foreign Affairs also called on OTA to address the ". . . newer technologies that can be brought to bear on such cooperative verification measures as manned on-site inspections, manned perimeter and portal monitoring, and unmanned on-site monitoring." The Committee added that "it would be useful to place these technologies in the broader context of verification technologies and methods." Since aerial surveillance is a potentially significant means of arms control monitoring, this report is one response to the latter request. (Another, *Verification Technologies: Managing Research and Development for Cooperative Arms Control Monitoring Measures*, was published in May 1991.)

The larger assessment has also produced two other, classified, reports: *Verification Technologies: Measures for Monitoring Compliance With the START Treaty* was delivered in the summer of 1990 and its unclassified summary was published in December 1990; *Monitoring Compliance With Limits on Sea-Launched Cruise Missiles* was delivered in the summer of 1991, with an unclassified summary scheduled for publication later in the year.

In preparing this report, OTA sought the assistance of several individuals and organizations (see "Acknowledgments"). We very much appreciate their contributions. As with all OTA reports, the content remains the sole responsibility of OTA and does not necessarily represent the views of our advisors or reviewers.

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

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Acronyms Used in Text

ACV	—Armored Combat Vehicle, cf. AIFV, APC, and HACV
AIFV	—Armored Infantry Fighting Vehicle, cf. ACV, APC, and HACV
APC	—Armored Personnel Carrier, cf. AIFV, ACV, and HACV
ATTU	—Atlantic Ocean to the Ural Mountains (Region)
CCD	—Camouflage, Concealment, and Deception
CD	—Conference on Disarmament
CFE	—Conventional Armed Forces in Europe
CSBM	—Confidence- and Security-Building Measures
CSCE	—Conference on Security and Cooperation in Europe
EMCON	—Emissions Control
GLCM	—Ground-Launched Cruise Missile
HACV	—Heavy Armored Combat Vehicle, cf. AIFV, APC, and ACV
ICAO	—International Civil Aviation Organization
ICBM	—Intercontinental Ballistic Missile
IIRS	—Image Interpretability Rating Scale
INF	—Intermediate-Range Nuclear Forces
IRBM	—Intermediate-Range Ballistic Missile
JSTARS	—Joint Surveillance and Tracking Reconnaissance System
MAD	—Magnetic Anomaly Detector
MEL	—Mobile-Erector-Launcher, cf. TEL
MRBM	—Medium-Range Ballistic Missile
NATO	—North Atlantic Treaty Organization
NTM	—National Technical Means
OSI	—On-Site Inspection
POE	—Point of Entry (Exit)
RDA	—Restricted Deployment Area
RPV	—Remotely Piloted Vehicle, cf. UAV
RV	—Reentry Vehicle
RVOSI	—Reentry Vehicle On-Site Inspection
SALT	—Strategic Arms Limitations Talks
SAR	—Synthetic Aperture Radar
SIGINT	—Signals Intelligence
SLAR	—Side-Looking Airborne Radar
SNF	—Short-Range Nuclear Forces
START	—Strategic Arms Reductions Talks
TEL	—Transporter-Erector-Launcher, cf. MEL
TERCOM	—Terrain Contour Matching
TLE	—Treaty-Limited Equipment, cf. TLI
TLI	—Treaty-Limited Item, cf. TLE
UAV	—Unmanned Aerial Vehicle, cf. RPV
WTO	—Warsaw Treaty Organization

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Chapter 1

OVERVIEW

Introduction

On May 12, 1989, President George Bush took a page from the history of the 1950s and called for establishment of an Open Skies regime. His proposal echoed and amplified the failed 1955 Open Skies proposal of President Dwight D. Eisenhower, calling for mutual overflights of sovereign territories[1] to provide common assurance as to the benign (or at least inoffensive) intentions and capabilities of the signatory nations. In its current incarnation, the Open Skies Treaty is being negotiated by the countries of the North Atlantic Treaty Organization (NATO) and the members of the now formally dissolved Warsaw Treaty Organization (WTO). Under conditions to be specified in the treaty, fixed-wing airplanes equipped with special sensing devices would fly over the territory of each treaty party in turn to provide a clearer picture of the status of the nation overflown.

The revival of Open Skies has also drawn attention to other uses for cooperative aerial surveillance in international agreements. (Open Skies is just one possible manifestation of cooperative aerial surveillance.) The idea of using cooperative overflights as a tool of international policy has not been completely dormant since the 1950s: it has been applied successfully in isolated instances (e.g., the Sinai and Antarctica[2]) and is currently being negotiated into a side agreement of the Conventional Armed Forces in Europe (CFE) Treaty.[3] But the acceptance of Open Skies negotiations, particularly by the Soviets, has led to a renewed willingness of governments to consider mutual overflights as a means of gathering information to promote a variety of goals, from confidence building and weapons counting to pollution monitoring and invasion warning.

The collection of information about other countries has historically been of great importance. In the case of the United States in the post-World War II era, government officials were particularly concerned about the growing Soviet threat and tried to obtain as much information about the Soviet Union as they could. President Eisenhower in 1955 sought to fill some of this informational void through his proposed Open Skies. However, Soviet secretiveness and continued rejections of cooperative measures led the United States to spend billions of dollars developing unilateral capabilities to collect information about the Soviet Union, especially regarding military preparations. These capabilities ranged from an early—and not particularly successful—use of camera-carrying weather balloons snapping pictures at random,[4] through airplanes (e.g., the U-2 of Francis Gary Powers), to those current collection practices (e.g., photoreconnaissance satellites),[5] known in an arms control context as national technical means (NTM) of verification. The superpowers may find in cooperative overflights unique qualities that could—under proper circumstances—suplement their NTM. Less technically advanced treaty partners that have not had the luxury of knowing as much about the world around them as the superpowers may look to cooperative aerial surveillance as a partial remedy.

During the late 1980s the opportunity, and to some extent the need, for cooperative aerial surveillance grew. Primarily, this was a result of "new thinking" and "glasnost" in the Soviet Union—the necessary prerequisites for what President Bush has heralded as the dawning of a "new world order."

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[1] The principle of a state possessing sovereign airspace over which it, and it alone, has control was established by the 1919 Paris Convention. The Chicago Convention of 1944 superseded the Paris Convention and provides the basis for modern international civil aviation. See Allen V. Banner, Andrew J. Young, and Keith W. Hall, *Aerial Reconnaissance for Verification of Arms Limitation Agreements: An Introduction* (New York, NY: United Nations, 1990), pp. 15, 30.

[2] Overflights of Antarctica do not violate sovereign airspace. Ibid., p. 22.

[3] The CFE Treaty itself contains limited provisions for brief helicopter overflights. The side agreement, dubbed "CFE IA," will, if agreed to, permit much more extensive and intrusive aerial observations.

[4] See Merton E. Davis and William R. Harris, *RAND's Role in the Evolution of Balloon and Satellite Observation Systems and Related U.S. Space Technology* (Santa Monica, CA: The RAND Corp., September 1988).

[5] "Photoreconnaissance satellites have become an important stabilizing factor in world affairs in the monitoring of arms control agreements. They make an immense contribution to the security of all nations."—President Jimmy Carter, in a speech at the Kennedy Space Center, Oct. 1, 1978.

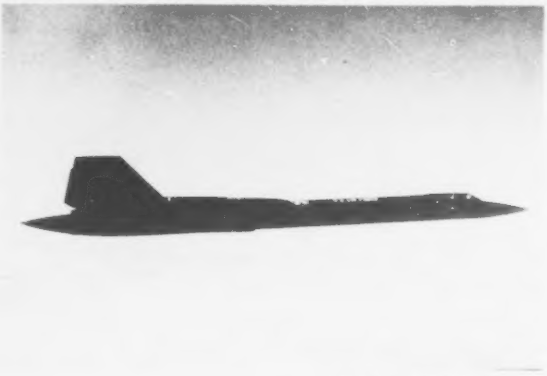

Photo credit: U.S. Air Force

The once-supersecret SR-71A Blackbird reconnaissance jet used high altitude and record-breaking speed to avoid interception as it gathered information for the U.S. defense and intelligence communities. The SR-71A was taken out of service in 1990.

During the late 1980s, the Soviet Government, under the direction of President Mikhail Gorbachev and then Foreign Minister Eduard Shevardnadze, developed a new foreign policy that emphasized cooperation over confrontation and realism over dogma. Not only did this policy loosen the Soviet grip on Eastern Europe and lay the groundwork for settlement of regional disputes, it also led to the negotiation of more extensive mutual confidence and security agreements. Cooperative measures, e.g., on-site inspections (OSIs) and cooperative aerial surveillance, which had previously been rejected by the Soviet leadership as overly intrusive, were declared acceptable. However, the optimism that crested in 1990 has ebbed in 1991. While Eastern European countries remain free, concerns have been raised in the international community about slowed withdrawals of Soviet troops, evidence of bad faith regarding the recently signed CFE Treaty,[6] and grumblings among Soviet reactionaries about "who lost Eastern Europe." Inside the Soviet Union, these same elements seem to be promoting a reassertion of Stalinist norms: iron discipline, restricted speech, militarism, and an antagonistic foreign policy.

In this environment where cooperation and competition coexist, negotiated agreements may:

- reduce tensions and build mutual confidence;
- limit, restrict, and reduce armaments;
- stabilize regional trouble spots;
- settle outstanding disputes; or
- provide for the monitoring of new environmental standards.

Without cooperation, no agreements would be possible, and if there were no concerns, no agreements would be necessary.

Cooperative aerial surveillance, if applied appropriately, could be a useful instrument for implementing some agreements and might add unique capabilities to the tool box that already includes NTM and cooperative measures, such as OSIs.

Americans, in concert with others, may someday be able to fly aircraft through the airspace of the Soviet Union and other countries on a reciprocal basis, taking pictures and collecting other data that will contribute to a more secure future. This report explores the many potential uses of cooperative aerial surveillance in international agreements and provides a basis for evaluating its applicability, effectiveness, and costs.

Summary of the Report

The Open Skies Treaty, which is being negotiated by members of NATO and the now disbanded Warsaw Pact, is intended to be primarily a confidence-building measure to reduce international tensions and foster trust and goodwill. Although there has been some talk of Open Skies flights assisting in the monitoring of other agreements, the provisions being negotiated are largely designed for their symbolic effect.[7] **In contrast, the possible inclusion of extensive and intrusive aerial surveillance measures in a CFE follow-on agreement (CFE IA) would augment other means of verification in determining compliance with the CFE Treaty limits.**

This report examines the application of cooperative aerial surveillance to these and other possible international agreements. Although the report often focuses on agreements that include the United States and the Soviet Union, the discussion is applicable to production plant) or they may be elusive (e.g., a mobile missile). They may be available for viewing at known times (e.g., weapon eliminations or the display of SS-25 launchers and sliding-roof garages provided for under the Intermediate-Range Nuclear Forces (INF) Treaty); or they may be spotted on a catch-as-catch-can basis (e.g., underground nuclear tests, which airborne "sniffers" could monitor for radiation leaks banned under the Limited Test Ban Treaty). The object being observed may, in fact, be an entire facility, perhaps closed as the result of an accord. If instituted, aerial monitoring flights are most likely to be included in arms control agreements, but they might also be used to monitor civil agreements (perhaps governing pollution levels). All these flights are intended to observe compliance with the provisions of an agreement, and through this observation deter, detect, and warn of significant violations. Aerial monitoring may also be used to assist other means of monitoring, such as NTM and OSI. **Aerial monitoring could take three**

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[6] See, e.g., "Figures Row Suspends CFE," *Jane's Defence Weekly*, Mar. 2, 1991, p. 290. The outstanding CFE issues now appear resolved.

[7] The Open Skies negotiating partners released a joint communique on Feb. 13, 1990 stating that Open Skies overflights "would contribute to the process of arms reduction agreements and existing observation capabilities." However, the parties have not as yet specified any agreements that Open Skies will support. (" 'Open Skies' Communique," *Official Text*, U.S. Arms Control and Disarmament Agency, Feb. 13, 1990.)

any combination of participants and to any region of the globe.[8] Conceivably, overflights might even be conducted by international organizations in much the same way OSIs are executed by the International Atomic Energy Agency. "Cooperative aerial surveillance" describes a collection of concepts for using sensors on airborne platforms as an important element of bilateral and multinational agreements. A party to an agreement providing for aerial surveillance would allow overflights of its territory in exchange for rights to similar flights over the territories of the other parties.[9]

Cooperative aerial surveillance, while generally thought of as involving only airplanes and cameras, could take many forms. Possible choices for aerial platforms include airplanes, helicopters, unmanned aerial vehicles, or lighter-than-air craft such as blimps. Sensor choices include photographic, electro-optical, and radar imaging devices, as well as radio receivers, air samplers, radiation or magnetic anomaly detectors, and acoustic devices. Different sensors' strengths and weaknesses make them suited to different inspection tasks, and the output of these sensors can be synergistically combined to let them see into one another's blind spots.

Cooperative aerial surveillance could be the subject of a stand-alone agreement in which the flights are both the means and the objective (as in Open Skies); it could be one provision among several supporting the ultimate goals of an agreement (as in CFE); or it could be the basis for an agreement that supports the goals of another agreement that does not itself provide for equivalent overflights (as in CFE IA).

Cooperative aerial surveillance has three main uses: mutual confidence building, aerial monitoring of specific targets or activities, and collateral information gathering (see figure 1-1). Confidence about another country's intentions and capabilities can be built when two or more states work cooperatively and open themselves to outside scrutiny. The Open Skies Treaty is an example of an agreement whose primary purpose would be to build confidence among the signatories.

"Aerial monitoring," as distinct from confidence building, is the process of observing from the air specific objects or specific activities (defined in terms of changes in or movement of discrete objects). These objects and activities may be found at known (perhaps declared) locations (e.g., a

Photo credit: U.S. Department of Defense, On-Site Inspection Agency

The United States and the Soviet Union first accepted the extensive use of on-site inspections as a treaty monitoring measure in the Intermediate-Range Nuclear Forces (INF) Treaty. Here, Soviet inspectors, center and right, conduct an inspection of the ground-launched cruise missile site at Molesworth, U.K.

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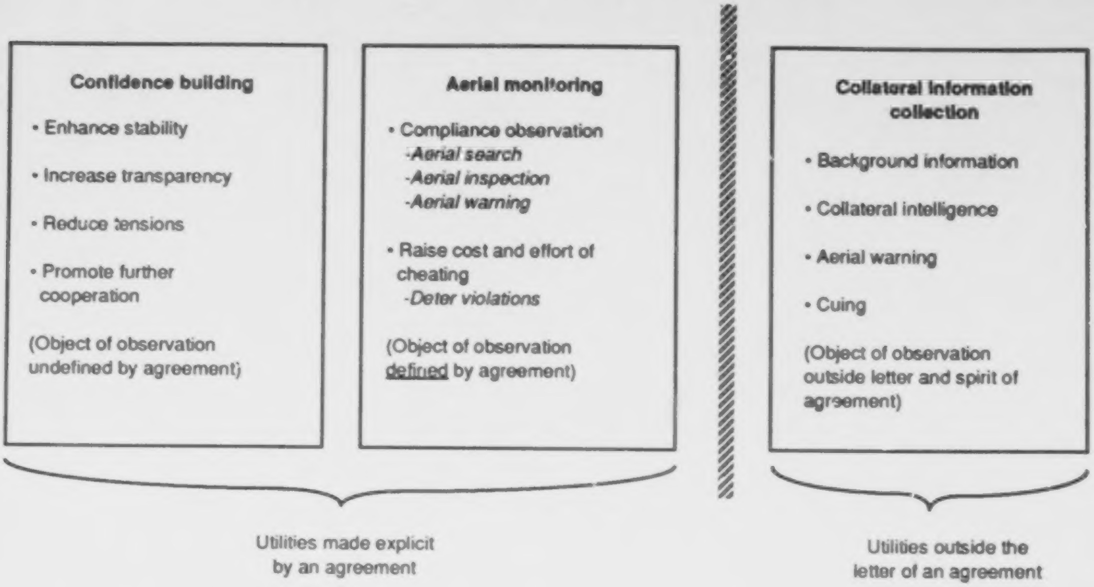
[8] For example, in May 1991 Hungary and Romania signed a bilateral aerial surveillance agreement calling for four overflights a year of each country. *The Arms Control Reporter: A Chronicle of Treaties, Negotiations, Proposals, Weapons, and Policy* (Brookline, MA: Institute for Defense and Disarmament Studies, 1991), p. 409.B.25.

[9] Military and intelligence flights over or parallel to the borders of a noncooperative nation are not included in this discussion.

Figure 1-1—Utilities of Cooperative Aerial Surveillance


Confidence building
• Enhance stability
• Increase transparency
• Reduce tensions
• Promote further cooperation
(Object of observation undefined by agreement)
Aerial monitoring
• Compliance observation
-Aerial search
-Aerial inspection
-Aerial warning
• Raise cost and effort of cheating
-Deter violations
(Object of observation defined by agreement)
Collateral information collection
• Background information
• Collateral intelligence
• Aerial warning
• Cuing
(Object of observation outside letter and spirit of agreement)
Utilities made explicit by an agreement
Utilities outside the letter of an agreement

SOURCE: Office of Technology Assessment, 1991.

forms: aerial search (looking for restricted objects or activities over a broad area); aerial inspection (observing objects or activities at designated inspection sites, as well as developing an overall assessment of the site); and aerial warning (alerting observers to threatening developments).

Aerial searches are intended to survey wide areas in order to provide information that will assist policy makers in making a determination of compliance with an agreement. These searches have two aspects: one is to locate and document legal objects and activities; the other is to detect objects or activities that violate an agreement. Even if aerial searches are unable to provide concrete evidence of violations, they might collect useful information that could be used to plan ground inspections or NTM observations.

Aerial inspection flights might resemble aerial searches over small designated sites or they might be used to:

- establish baseline counts and documentation of treaty-limited items (TLIs);
- conduct preparatory work for OSIs by developing site maps and pinpointing the most promising search strategy;[10]
- document the elimination of large TLIs and monitor their status;[11]
- monitor the status of closed-out facilities and bases; or
- monitor the perimeter around a facility before an OSI team can arrive.

Besides monitoring the number or existence of certain objects and activities, aerial monitoring might provide warning of potentially hostile acts. This warning might result from discovering too many objects, too much activity, or the presence of objects and activity at restricted sites. Conversely, the absence of legitimate objects or activities at designated areas might constitute warning that they are somewhere more threatening. Functionally similar to aerial searches or aerial inspections, aerial warning flights could observe compliance with military exclusion zones, border restrictions, or

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[10] Amy Smithson and Michael Krepon, "Strengthening the Chemical Weapons Convention Through Aerial Monitoring," Occasional Paper No. 4, The Henry L. Stimson Center, Washington, DC, April 1991, pp. 15, 18-25.

[11] For example, under the SALT II Treaty, retired bombers were cut up and placed out in the open so that NTM satellites could verify their elimination.

Photo credit: U.S. Department of Defense, On-Site Inspection Agency

In a spectacular display, a Soviet SS-12 missile is eliminated by explosion in accordance with the INF Treaty.

military exercise limitations (and in fact aerial surveillance already has been used this way, for example, in the Sinai).

Overflights could also be used to gather information beyond the letter and spirit of an agreement. Indeed, the gathering of some such information would be hard to avoid. The use of this collateral information could support the stated goals of the agreement, or it could serve other intelligence purposes, e.g., strategic assessment, targeting, and general warning. Because of fears of spying, negotiators may seek to limit the gathering of collateral information to an absolute minimum by placing restrictions on overflights and the equipment carried aboard. **Controlling the costs associated with the loss of collateral information to a military, political, or even economic adversary may be more important to a country than the financial costs of an overflight regime.**

The advisability of agreeing to aerial surveillance would depend on the goals of the agreement in question, the capability of overflights to accomplish the missions set for them, a comparative analysis of different combinations of information-gathering options (e.g., NTM and OSI), and the costs and benefits of the overflights. Potential aerial surveillance regimes can range from the purely symbolic to complete openness with correspondingly high intrusiveness.

An understanding of cooperative aerial surveillance issues can be useful to Congress because:

- Two agreements that may include cooperative aerial surveillance (Open Skies and CFE IA) are under negotiation, though talks are currently stalled. The Senate may be asked for its advice and consent on one or both of these, and the Congress as a whole will be asked to fund any implementation.
- Cooperative aerial surveillance is a relatively new form of information gathering that may be useful as a supplement to NTM or other cooperative measures (e.g., OSI). As such, it could be incorporated into a wide variety of current or future international accords governing anything from arms control monitoring and border patrols to radiation and pollution measurements.
- A study of aerial search, in particular, illuminates some of the complexities inherent in all types of searches. This knowledge, therefore, provides a basis for evaluating search by NTM.
- Witnesses testifying before Congress on the topic of arms control treaty verification are often pressed to quantify what they mean by such statements as "If the Russians cheated, we would be 90 percent sure of catching them, given enough time." Though most such estimates are impressionistic, and best taken as figures of speech, some have a possible empirical basis. In the context of aerial search, this report illustrates how such estimates could be generated and interpreted.

This report addresses both the diplomatic and the technical aspects of cooperative aerial surveillance as a tool of international cooperation, and it builds a foundation for evaluating the costs, benefits, and effectiveness of aerial surveillance regimes. In particular, it examines the possible provisions currently being negotiated for overflights in the Open Skies and CFE IA treaties,[12] which may have much in common procedurally and technically when the actual provisions are agreed upon.

Unlike arrangements that might focus on building confidence alone, an aerial *monitoring* regime lends itself to rigorous analysis. The selection of aerial platforms and sensor suites and the monitoring procedures can all be optimized for the targets in question.

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[12] Neither treaty was completed at the time of this writing, and drafts of each remain internal executive branch working documents, unavailable to legislative branch staff (and thus OTA) until signed by the President.

Important points in the negotiation of an agreement to permit aerial monitoring would include limitations on the number, frequency, and territorial scope of overflights. Negotiators might also agree to restrictions on the capabilities of sensors and data storage. They would need to create an inspection protocol that recognized and limited the potential for camouflage, concealment, and deception before a flight can arrive.

The chances that aerial monitoring will function as hoped are lessened by the difficulties presented by the task of discriminating illegal targets (e.g., covert missile launchers) from legitimate ones (e.g., flatbed trucks), the potential mobility of the targets, and the desire to detect cheating before it becomes significant. Under some plausible restrictions, aerial monitoring could be so perfunctory as to be of symbolic value only—perhaps providing a false sense of confidence. At the other extreme, flights that provide much useful information might be too intrusive to tolerate.

As noted above, aerial monitoring of treaty compliance could perform search, inspection, or warning functions. Chapter 6 and its associated appendices A, B, and C apply quantitative analysis to one of those functions: aerial search.[13] Focusing on this one mission permits OTA to illustrate:

- how quantitative methods can be applied to the larger problem of estimating confidence levels in our ability to find treaty violations if they exist;
- how comparisons could be made among various monitoring options to produce more cost-effective monitoring regimes; and
- the importance of applying multiple, complementary instruments to monitoring tasks.

In the case of a wide-area search, any single flight—even a relatively intrusive one—would be unlikely to catch a treaty violation, for several reasons. First, the overflown party might not be cheating (perhaps as a result of the prospect of overflights). Second, if the overflown party is cheating, the illicit objects or activities would probably be restricted to a region that is relatively small when compared to the nation as a whole: because of the limitations of the airborne platform, any one flight could probably cover only a small percentage of the territory subject to overflights. Without knowing where to look, the probability of finding the violation would be relatively small. Third, given sufficient prior notice and information about how a flight is to be conducted, the cheater could take steps to minimize the chances of being observed through camouflage, concealment, or deception, so that violations would be missed even if they were inside the region inspected by a flight.

Photo credit: U.S. Department of Defense

The existence of small, off-road-capable, mobile missile launchers, like this Soviet SS-20, has made the task of monitoring covert deployments more difficult. SS-20s have been eliminated as part of the INF Treaty.

To be reliable, a program of aerial search would need a series of flights to compensate for the relative unlikelihood that any one flight would catch a violation if it existed. Prior information about the characteristics of the target could narrow the region to be searched and thus lessen the reliance on chance alone. Several kinds of prior information can be helpful: the results of previous aerial searches; the outputs of other information sources, e.g., NTM, OSI, and other types of aerial monitoring; the natural constraints provided by topography and weather, as well as the additional constraints imposed by infrastructure; and a sense of the overflown side's operational practices and doctrine. The full use of such prior information is one of the skills of the *photointerpreter*, an artisan whose craft remains largely unautomated.

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[13] Note that aerial warning is closely related to aerial search and that many of the same principles apply.

The most difficult part of using information gathered by aerial search (or, indeed, any other means) in treaty verification is deciding what to make of a continuing stream of reports that no cheating has been found. *Bayesian statistics*, a recently revived[14] body of early statistical thought, allows the incorporation of such negative evidence into a continuously updated view of the situation. Bayesian calculations make possible the form of expert testimony that decisionmakers want most: "Based on the fact that we haven't seen any cheating, on the probability that we would have seen it if it were going on, and on our original estimate of how likely it was that they would cheat, we assess that there is an *x* percent chance that they are violating the treaty."

Although the prospective Open Skies Treaty is primarily intended to build mutual confidence among its signatories, it is also presented by some of the participants (and indeed, the aforementioned joint communique) as helpful for monitoring provisions of other, particularly arms control, agreements. As an illustration, OTA applied the publicly released Open Skies overflight provisions to the task of monitoring Soviet mobile missiles of the types covered by the Strategic Arms Reductions Talks (START). OTA's analysis, while preliminary, suggests that the number of flights would be far too few to make an exhaustive search of the Soviet Union. However, their measurable chance of uncovering a sizable violation—should it exist—in a matter of months would loom large in the minds of Soviet planners. The chances that flights would find a violation—should it exist—would be raised if the use of prior information obviated the need for exhaustive search of the entire Soviet Union. Flights could cue NTM as well as be cued by them.

The mobile missiles limited by START are not the only possible items of interest to arms control treaty verifiers. Some other topics, e.g., the location and status of declared sites, the absence of undeclared fixed facilities, and the location or movement of large-scale military formations, could be readily investigated by a program of aerial monitoring. Nor is the utility of overflights limited to search—for example, flights could aid in the monitoring of START or START-like provisions by loitering over the site of a challenge inspection while an OSI ground team was on the way, or provide clues as to the best locations to conduct such inspections.

Photo credit: U.S. Department of Defense

After data has been gathered by an aerial surveillance flight, the arduous task of sifting, sorting, and analyzing the data commences. In the case of imagery, highly skilled photointerpreters must carefully examine each frame for valuable information.

Organization of the Report

Chapter 2 of this report presents an overview of the utilities of cooperative aerial surveillance—both good and bad—and discusses the interaction of cooperative aerial surveillance with other means of information gathering, most notably NTM and OSI. Chapter 3 surveys the types of airborne platforms and sensors that might be applied to a prospective overflight regime and raises some of the issues associated with their use. In chapter 4, Open Skies is discussed as both the source of renewed interest in using overflights as an instrument of international relations and as a prime example of the use of cooperative aerial surveillance as a means of building international confidence. Chapter 5 looks at other possible applications of cooperative flights in agreements designed, inter alia, to build confidence, monitor arms and environmental restrictions, and safeguard borders. Through a discussion of the capabilities and limitations of broad area search, chapter 6 builds an analytical framework for evaluating overflight monitoring regimes using quantitative methods and Bayesian statistics. The first three appendices to this report continue the quantitative discussion. The final appendix records NATO's initial Open Skies proposal.

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[14] M.G. Bulmer, *Principles of Statistics* (New York, NY: Dover, 1979), pp. 169-176, especially p. 176. See also Steven M. Stigler, *The History of Statistics: The Measurement of Uncertainty Before 1990* (Cambridge, MA: Belknap Press, 1986).

Chapter 2

WHY AERIAL SURVEILLANCE?

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Chapter 2

WHY AERIAL SURVEILLANCE?

Summary

Cooperative aerial surveillance could be the subject of a stand-alone agreement in which the flights are both the means and the objective (as in Open Skies); it could be one provision among several supporting the ultimate goals of an agreement (as in the Conventional Armed Forces in Europe Treaty (CFE)); or it could be the subject of an agreement that supports the goals of another agreement that does not itself provide for equivalent overflights (as in CFE IA).

Aerial surveillance has three main uses: mutual confidence building; aerial monitoring of specific targets, sites, or activities; and collateral information gathering. Confidence building and aerial monitoring would be explicit functions written into an overflight regime, whereas the collection of collateral information is an implicit byproduct contrary to the spirit of an agreement. Aerial monitoring can be used to search for, inspect for, deter, detect, and warn of noncompliant behavior, as well as to provide information that might assist other means of monitoring. Collateral information can supplement agreed sources of information about treaty compliance or it can be used for other intelligence purposes, e.g., strategic assessments, targeting, and general warning.

Aerial surveillance can work collectively and synergistically with on-site inspections (OSIs), other cooperative measures, and national technical means (NTM) of verification. The decision to include aerial surveillance in an accord would depend on the goals of the accord, an assessment of the relative strengths and weaknesses of the different monitoring options, the costs and benefits of the regime, interactions with other agreements, and negotiability.

Introduction

In 1955 President Dwight D. Eisenhower proposed "Open Skies," a plan for an international program of reconnaissance flights intended to reduce fears of surprise military attack. The Soviet Government rejected this proposal as a U.S. effort to spy on the Soviet Union. But after President George Bush revived the proposal in May 1989, a transformed Soviet Union seemed more receptive. It agreed to interalliance negotiations on an Open Skies Treaty to build mutual confidence. The same 23 nations[1] were already negotiating provisions for cooperative aerial surveillance[2] as part of the CFE Treaty's compliance monitoring regime.

The Open Skies negotiations eventually stalled and the CFE Treaty was signed on November 19, 1990, without extensive aerial monitoring provisions (though further negotiations—CFE IA—may yet add such provisions).[3] The fact that these cooperative aerial surveillance negotiations took place reflects the promise of the idea; their inconclusiveness reflects the difficulties of designing an overflight regime that would satisfy the goals and concerns of different nations.

This chapter qualitatively examines the utility of aerial surveillance in supporting the goals of an agreement.[4] Depending on how they are implemented, overflights can build confidence in the inoffensiveness or benignancy of the other parties, monitor agreements, or gather collateral information. This chapter also explores the interaction of aerial surveillance with NTM and OSI.

What Is Cooperative Aerial Surveillance?

"Cooperative aerial surveillance" describes a collection of concepts for using sensors on airborne platforms as an important element in bilateral and multinational agreements. A party to an agreement providing for aerial surveillance would allow overflights of its territory in exchange for rights to similar flights over the territories of the other parties.[5]

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[1] This number became 22 with the unification of Germany in October 1990.

[2] For the purposes of this report, "aerial surveillance," "aerial observation," and "aerial reconnaissance" are regarded as synonymous and encompass all types of airborne observation described.

[3] When the CFE Treaty enters into force, it will be verified by NTM and cooperative measures, such as OSIs. Aerial inspections will be included, but they will be limited to brief host-operated helicopter flights over inspection sites. These overflights are much less extensive and intrusive than those under consideration for CFE IA. The signing of CFE before the completion of all its aerial monitoring provisions implies that the CFE IA flights may serve a more supplementary, than critical, role in verification.

[4] Aerial monitoring, in particular, lends itself to quantitative analysis. The foundations for such an analysis are presented in chs. 3 and 6.

While generally thought of as involving only airplanes and cameras, cooperative aerial surveillance could take many forms. Possible choices for aerial platforms include airplanes, helicopters, unmanned aerial vehicles (UAVs), or lighter-than-air craft such as blimps. Sensor choices include photographic, electro-optical, and radar imaging devices, as well as radio receivers, air samplers, radiation or magnetic anomaly detectors, and acoustic devices. The selection of platform and sensor will depend on the nature of the agreement being negotiated.

Cooperative aerial surveillance could be included in an agreement in three general ways: it could be both the means and the objective (as in Open Skies); it could be one provision among several supporting the ultimate goals of an agreement; or it could be the basis for an agreement that explicitly supports the goals of another agreement that does not itself provide for overflights.

Although this report focuses primarily on negotiations of which the United States and the Soviet Union are a part, the principles discussed would be equally applicable to any set of nations.

The Utility of Aerial Surveillance

Cooperative aerial surveillance could have three main uses in an international accord: mutual confidence building, aerial monitoring of specific targets or activities, and collateral information collection (see figure 2-1). Confidence building and aerial monitoring are legitimate functions, which follow the letter and spirit of an accord. The collection of collateral information is a generally unavoidable byproduct of an overflight regime which tries to restrict either the quantity or quality of the data collected.

Confidence about the inoffensiveness or benignancy of another country's intentions and capabilities can be built when two or more states work cooperatively and open themselves to outside scrutiny. The Open Skies Treaty is an example of an overflight regime whose primary purpose would be to build mutual confidence among the signatories. The phrase "confidence building" is fairly amorphous, but captures a range of positive concepts, e.g., a reduction of tensions, greater transparency, and the development of common understanding through increased contact and openness.

"Aerial monitoring," as distinct from confidence building, is the process of observing from the air specific objects, sites, or activities (described by the movement of discrete objects). The objects and activities may be declared with their locations known (e.g., a production plant), or they may be mobile and difficult to see. Aerial monitoring flights are likely to be included in arms control agreements to search for, inspect for, raise the cost of, deter, detect, or warn of compliance violations as well as to provide information that might assist other means of monitoring, but flights can also be used to monitor civil agreements (e.g., pollution levels).

Overflights could also be used to gather information beyond the letter and spirit of an agreement. Indeed, the gathering of some such information would be hard to avoid. The use of this collateral information could support the stated goals of the agreement, or it could serve other intelligence purposes, e.g., strategic assessments, targeting, and general warning. Because of fears of spying, negotiators may seek to limit the gathering of collateral information to an absolute minimum by placing restrictions on overflights and the equipment carried aboard.

There are only two instances in which the utility of the overflights and the purposes of an agreement might coincide completely, but these are extreme cases that will not likely form the basis for a negotiable agreement. First and most simply, parties to the agreement could recognize and legitimate the broad capabilities of aerial surveillance. The parties could then gather as much information as the negotiated sensors would allow. By definition, there would be no collateral information to gather, since all information would be fair game. At the other extreme, exceptionally tight controls could be placed on the inspection team, aircraft, sensors, and data to ensure that only information related to the agreement would be gathered and processed.

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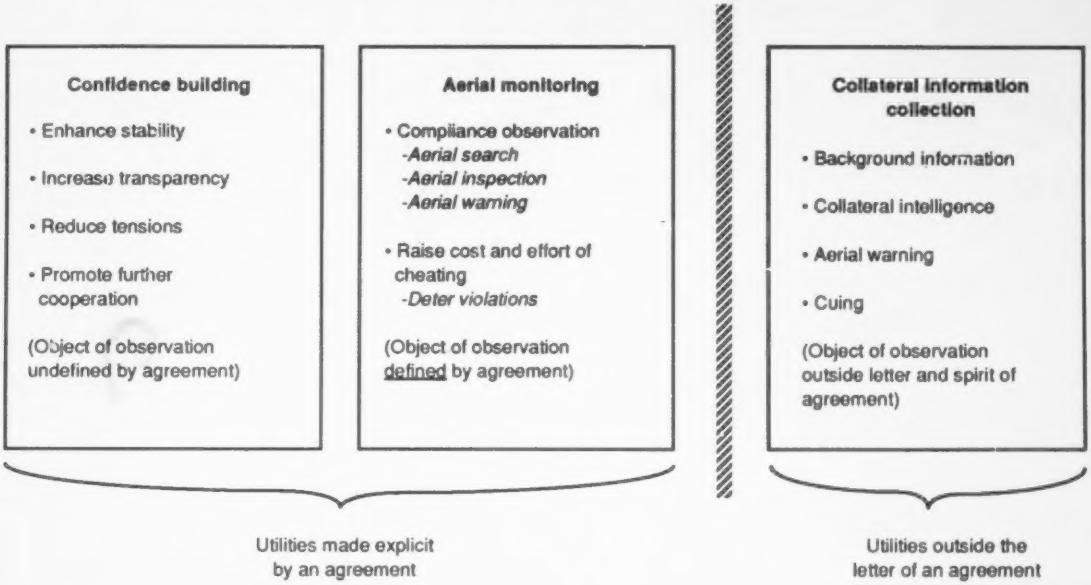
[5] Military and intelligence flights over or parallel to the borders of a noncooperative nation are not included in this discussion.

Figure 2-1—Utilities of Cooperative Aerial Surveillance


Confidence building
• Enhance stability
• Increase transparency
• Reduce tensions
• Promote further cooperation
(Object of observation undefined by agreement)
Aerial monitoring
• Compliance observation
-Aerial search
-Aerial inspection
-Aerial warning
• Raise cost and effort of cheating
-Deter violations
(Object of observation defined by agreement)
Collateral information collection
• Background information
• Collateral intelligence
• Aerial warning
• Cuing
(Object of observation outside letter and spirit of agreement)
Utilities made explicit by an agreement
Utilities outside the letter of an agreement

SOURCE: Office of Technology Assessment, 1991.

Negotiators are unlikely to agree to these two extreme cases. They are more likely to pursue restrictions on both the methods of information collection and the type of information collected. Parties will negotiate a middle ground, trading some benefits of confidence building or monitoring for some losses of collateral information. Striking this balance is perhaps the most difficult challenge facing overflight regime designers.

Confidence Building

The role of aerial surveillance in confidence building is epitomized in the current negotiations over an Open Skies Treaty. The stated goal of Open Skies is primarily confidence building. The framers of this treaty do not envision it as an arms control agreement that uses aerial surveillance to monitor limits on military hardware or activities. Instead, they have argued simply for greater international openness on the grounds that transparency leads to enhanced stability and predictability, reduced tensions, and international cooperation, and lays the foundation for future, more specific arms control measures.[6]

The potential for aerial surveillance to gather information about the inspected party is great. To the extent that this information corroborates positive declarations and policies or deters undesirable behavior, the agreement can be said to enhance stability, reduce tensions, and thus build general confidence. To the degree that this information would be able to reveal in a timely fashion duplicity or bad faith, should such occur, confidence is built in the agreement itself.[7] Ironically, if such duplicity is discovered, it would, at least temporarily, exacerbate instability and tensions. (See figure 2-2.)

The confidence-building aspect of aerial surveillance is also reflected symbolically in nations pursuing common goals, in multinational inspection teams (possibly dominated by military personnel)

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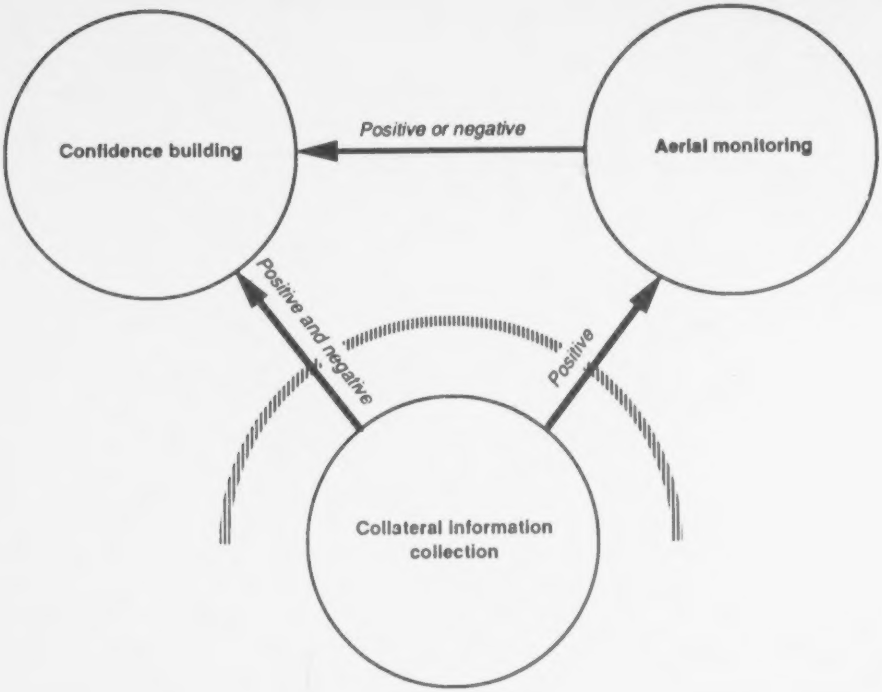
[6] The Open Skies negotiating partners released a joint communique on Feb. 13, 1990 stating that Open Skies overflights "would contribute to the process of arms reduction agreements and existing observation capabilities." However, the parties have not as yet specified any agreements that Open Skies will support. This differs from an agreement like CFE that includes limited helicopter surveys of inspection sites or the CFE follow-on treaty (dubbed "CFE IA") currently being negotiated that is explicitly designed to provide monitoring of CFE restrictions. Open Skies is discussed in ch. 4; CFE and CFE IA are discussed in ch. 5. (" 'Open Skies' Communique," *Official Text*, U.S. Arms Control and Disarmament Agency, Feb. 13, 1990.)

[7] The detection of cheating does not necessarily mean that a treaty is flawed. It may be that this level of activity would not have been detectable without the monitoring provisions of the treaty. The cheating does, however, require some appropriate response including possibly the abrogation of the treaty.

Figure 2-2—Interaction of Utilities



SOURCE: Office of Technology Assessment, 1991.

working side-by-side, and in laying groundwork for more ambitious cooperative efforts.

Confidence building is likely to be a part—either as a primary goal or as a side benefit—of all potential agreements that include provisions for cooperative aerial surveillance. For example, mutual aerial surveillance of nuclear reactors to ensure their safe operation might have the specific utility of measuring reactor radiation levels, but they might also foster a cooperative atmosphere. The only instances where confidence might be undermined by overflights of countries following both the spirit and the letter of an agreement (i.e., compliant countries) would occur when a signatory has underestimated the potential of overflights to be used against it for gathering collateral information (see below).

Aerial Monitoring

Aerial monitoring is the process of observing from the air objects, sites, or activities (described by the movement of discrete objects) that have been specifically designated in an agreement. Because the subject of observation is explicitly defined (e.g., a tank, a chemical plant, a combined-arms exercise), negotiations over airborne platforms and sensors can be based to a larger degree on objective criteria. For example, an agreement that seeks to count individual tanks must provide for sensors that at a minimum can distinguish a tank from an automobile. In general, aerial monitoring regimes can be subjected to quantitative analyses (e.g., the number of flights needed to search a given area, the minimum requirements for a sensor suite) more readily than overflights intended only to build confidence. Theoretically, this should make negotiations somewhat clearer.

Parties to an agreement with provisions that require verification could employ aerial monitoring for purposes of search, inspection, or warning. Aerial monitoring could also, by its very presence, raise the expense of, and possibly deter, cheating.

Photo credit: U.S. Department of Defense, On-Site Inspection Agency

Working side-by-side, inspectors and their escorts sometimes develop a better understanding of their former adversaries and perhaps even mutual respect. Here, the Soviet inspection team chief and his American escort counterpart sign the official report that marks the completion on an Intermediate-Range Nuclear Forces Treaty inspection.

Compliance Observability

An agreement that includes numerical limits, bans, or restrictions on actual weapons, equipment, facilities, or activities may permit aerial monitoring to observe compliance. Compliance observability is most often discussed in the context of arms control agreements. However, there are many potential applications for aerial monitoring where it might be desirable to observe activities or objects that have little or nothing to do with traditional arms control (e.g., peacekeeping or pollution monitoring).

Aerial monitoring, as used in this report, encompasses the narrower terms: "aerial search," "aerial inspection," and "aerial warning." Aerial search refers to overflights that survey wide areas to detect and determine the legitimacy of specified objects or activities. Aerial inspection differs from aerial searches only in that it focuses on objects or activities at specific sites. Aerial warning also involves the observation of specific activities, objects, or sites, but with the intent to warn of threatening acts. These distinctions are artificial and partially overlap, but they are a useful tool in clarifying the discussion.

Aerial Search[8]—Aerial searches are intended to survey wide areas in order to provide information that will assist policymakers in making a determination of compliance with an agreement. These searches have two aspects: one is to locate and document legal objects and activities; the other is to detect objects or activities that violate an agreement. For example, an agreement might allow a certain number of objects, which aerial search could help count. If the objects were entire facilities (e.g., Intercontinental Ballistic Missile (ICBM) silos or chemical plants) or large-scale activities (e.g., division-sized exercises), this might be a relatively straightforward mission. Smaller and relocatable treaty-limited items (TLIs), e.g., cruise missiles, would add more difficulties.[9] If monitoring is possible at all from the air, it might be facilitated by focusing on chokepoints that the TLI must pass through (e.g., a final assembly plant, a bridge, or a railroad junction), or by remotely reading active tags on the TLI.[10]

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[8] See ch. 6, which builds an analytical framework for examining the effectiveness of aerial search.

The second aspect of compliance observability is to ensure that the observed party is not significantly violating the provisions of an accord through the possession of prohibited items or the conduct of restricted activities. As above, the size and mobility of the TLIs in question is often important. Most troublesome are small and mobile TLIs that can be concealed or moved before an overflight. Under a plan suggested by North Atlantic Treaty Organization (NATO) for Open Skies, the amount of time an illegal TLI would have available to hide would be 46 hours plus the time to fly to the TLI if concealment began at the time of flight notification, or 24 hours plus the time to fly to the TLI if this concealment began with the filing of the flight plan. (See discussion in ch. 4.) Clearly, this would an ineffective interval for detecting easily hidden, illegal TLIs. Thus, negotiators must take such timelines into account when deciding to include an aerial surveillance option and adjusting it to fit the TLI under observation. The interval must be short enough to detect cheating or at least to flush the TLI into the open for detection by other means.[11]

For some classes of objects or activities, signatures other than size are most important for violation detection. For example, a plant releasing restricted pollutants might be detectable not so much by its dimensions, but rather by its effluents. Air samplers on aircraft might be able to detect these emissions or their residue if the time it takes for the aircraft to arrive is less than the time for the emissions to dissipate after the violator shuts down operations.

Even if aerial searches are unable to provide concrete evidence of violations, they might collect useful information that could be used to plan ground inspections. (For more on the interaction of OSI and aerial surveillance, see below.)

Photo credit: U.S. Central Intelligence Agency

In the 1962 Cuban missile crisis, military reconnaissance aircraft were used to search for and document Soviet medium-range nuclear missile emplacements. This photograph of a missile preparation area was taken at an altitude of about 250 feet, and at the speed of sound.

Aerial Inspection—Potential aerial inspections differ from aerial searches in that they seek to monitor compliance at known (and often treaty-designated) locations. Some aerial inspections might closely resemble a search, only over a smaller region. For example, photographs taken by the inspection team from a helicopter might be used to look for illicit TLIs within the grounds of a restricted deployment area. However, other types of aerial inspection might be very different. Among other things, they might be used to:

- establish baseline TLI counts and documentation;
- conduct preparatory work for OSIs by developing site maps and pinpointing the most promising search strategy;[12]

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[9] See ch. 6 for a quantitative discussion of the challenge of searching for such TLIs from the air.

[10] See box 2-C.

[11] Safety and logistical reasons will limit the reduction of this interval, as may security concerns.

[12] Amy Smithson and Michael Krepon, "Strengthening the Chemical Weapons Convention Through Aerial Monitoring," Occasional Paper No. 4, The Henry L. Stimson Center, Washington, DC, April 1991, pp. 14, 17-23.

- document the elimination of large TLIs and monitor their status;[13]
- monitor the status of closed-out facilities and bases; or
- monitor the perimeter around a facility before an OSI team can arrive.

Aerial Warning—Besides monitoring the number or existence of certain objects and activities, aerial monitoring might be written into an agreement to provide warning of hostile acts. This warning might be the product of discovering too many objects, too much activity, or the presence of objects and activity at restricted sites; or conversely, the absence of legitimate objects or activities from designated areas with the implication that they might be somewhere more threatening. Functionally similar to aerial searches or aerial inspections, aerial warning flights could observe compliance with military exclusion zones, border restrictions, or military exercise limitations. Unlike confidence-building flights, warning flights would be explicitly tailored to sense a specific set of objects or activities (defined by objects). (See ch. 5 for some current and potential examples of aerial warning.)

One of the chief concerns of any party to a militarily significant agreement, and the predominant reason for its monitoring regime, is the threat of a dramatic breakout from the terms of an agreement by another party. Breakout can be defined as a violation of an accord so rapid as to confer a militarily significant advantage before the other side(s) has time to react. No agreement can prevent a party from attempting a breakout; however, a good monitoring regime and effective intelligence could make successful breakout impossible by being able to detect the intended action with sufficient time to respond, thus providing strategic warning.[14] (Responses could be diplomatic, economic, or military; and reciprocal or asymmetric.[15])

Make Cheating More Difficult and Expensive

A side benefit of being able to observe compliance from an aircraft is that any attempt by a country to cheat on an agreement, even if the violation is not in the end detected, is necessarily more difficult and expensive than if overflights were not permitted. This is because the violator must expend some effort to avoid detection. If the agreement were poorly formulated or if the sensors carried aboard the aircraft were inadequate, this effort might be minimal (e.g., raising a camouflage net).[16] However, if the agreement were designed with potential evasion paths in mind, the difficulty and expense of cheating might be raised to some deterrent level (e.g., by forcing the violator to avoid a TLI's legal manufacturing, testing, and support infrastructure, and to build an entire covert one). The idea is to make the anticipated gain of cheating not worth the effort (see box 2-A). Note that an agreement that does not restrict or allow the inspection of sensors has the greatest deterrent potential since the overflown country can only guess at the capabilities onboard and would probably be inclined to make a conservative estimate.[17]

Collateral Information Collection

Another utility of overflights is the gathering of information not specifically mandated by an accord (what the Soviets have sometimes labeled spying).[18] This collection is very hard for both the host country and the observers to limit. For example, a flight looking for a missile silo may take hundreds of square miles' worth of photographs for every hundred square feet of silo. Similarly, an air sampling spectrometer may reveal more compounds than just the ones subject to the accord. At a minimum, the inspectors aboard a plane must be allowed to confirm visually that the plane is following its

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[13] For example, under the SALT II Treaty, retired bombers were cut up and placed out in the open so that NTM satellites could verify their elimination.

[14] The national intelligence community would have responsibility for detecting militarily significant developments with or without a treaty.

[15] Reciprocal responses sometimes have the negative quality of allowing the violator to control the arena of competition. For example, if a party with a dominant air force violates a conventional arms accord by building extra attack aircraft, it might make more sense for a less sophisticated cosignatory to build up antiaircraft batteries, rather than build a like number of relatively inferior planes.

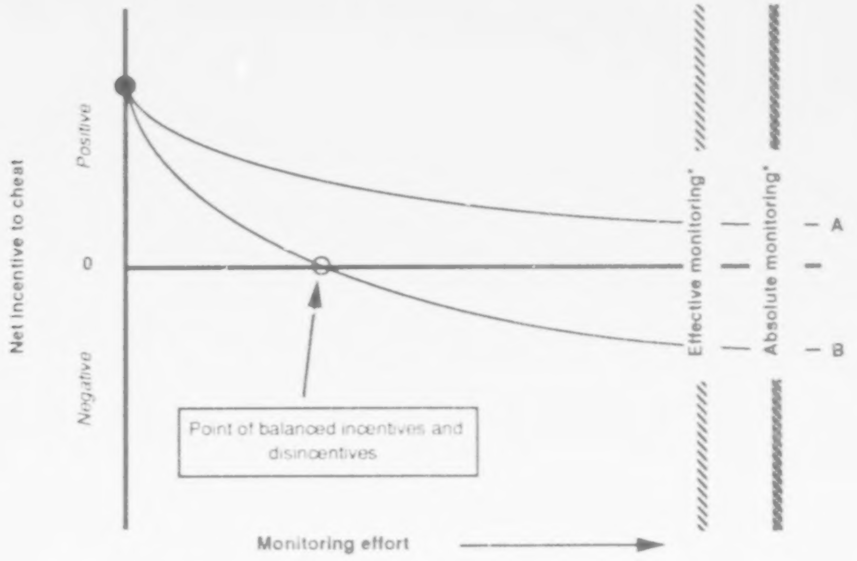
[16] Of course, if compliance were not observable from the air, overflights would have no deterrent value, and might in fact act to make the overflying nation unjustifiably confident.

[17] If a country did not make an accurate estimate and chose to cheat, its violation would likely be detected. (See Smithson and Krepon, op. cit., footnote 12, p. 4.)

[18] The Office of Technology Assessment does not endorse the collection of collateral information, but presents it as an important factor in determining the risks and benefits of aerial surveillance.

Box 2-A—Balancing Monitoring and Incentives To Cheat

The conceptual graph below depicts two general cases of how the balance of incentives might be related to the monitoring provisions of an agreement. The curves generated by the examination of a real treaty are bound to be much more complex, with many nuances and ambiguities.



*Effective or absolute monitoring may not be possible for all agreements.

SOURCE: Office of Technology Assessment, 1991.

The characteristics of the object or activity to be monitored and how they fit into the monitored country's security arrangements, as well as the propensity of the country toward cheating, provide the starting point on this graph. This point is the net incentive to cheat on the agreement in the absence of all monitoring. In this graph, the more interesting example of a positive net incentive without monitoring is described, but for some violations there may be no incentive to cheat at all.[1]

Curve A depicts the case where no amount of monitoring will lower the net incentive to cheat to zero. This might occur when violations are too easily hidden to monitor effectively, when the positive incentives to cheat are extraordinarily high, or when the cost of getting caught is comparatively low. Even if effective monitoring (defined as monitoring that detects any significant violation in time to respond) or absolute monitoring (defined as monitoring that detects all cheating) are possible—and not all potential agreements can be effectively monitored, the positive incentives to cheat continue to outweigh the disincentives.[2] In this case, the best that can be hoped for is an agreement that provides, at a minimum, an effective monitoring effort.

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[1] If the monitored country imputes no value to the treaty, then this point would equal the net incentive to engage in the restricted activity (e.g., build another bomber) without the agreement. However, if the country values the agreement on its own merits, then the country will have a lower incentive to engage in the restricted activity than it did without the agreement. In some cases, the legal and moral imperative of the treaty itself may be enough to lower the incentive to cheat below zero. On the other hand, the existence of an agreement might actually raise the net incentive to cheat above the preagreement level if mutual restrictions opened new opportunities for gaining strategic advantages. For example, building another bomber might make little sense if the other side were doing the same; however, an advantage might be gained by building that same bomber if the other side were abiding by an agreement not to do so.

[2] This graph also illustrates how the monitoring party might unwisely squander limited monitoring resources by paying for monitoring beyond what is required for deterrence, or effective or absolute monitoring.

Curve B illustrates the case where some amount of monitoring lowers the incentive to cheat past the level of indifference (i.e., the zero line where incentives and disincentives are balanced) until the costs and difficulties of cheating offset the expected benefits. It is in this region below the indifference line where deterrence operates. An agreement might be considered to have sufficient monitoring if the net incentive to cheat could be forced into this negative region, regardless of whether or not the monitoring regime was deemed "effective" or "absolute."

Of course, the real world is more complicated than this. The incentive structure of the monitored party and how it varies with increasing monitoring is hard for the monitoring party to gauge. Because of this element of uncertainty, a real graph would be less well defined and the monitoring party would want the disincentives to cheating to fall well below the line of indifference, rather than just across it. Moreover, the monitoring party must be prepared for sudden shifts in the incentive structure—shifts that would void the deterrent value of monitoring.

proper path and not being flown off course by its host country pilots, should they be piloting.[19]

The definition of what constitutes collateral information in an aerial monitoring regime is relatively simple since the objects of observation (e.g., tanks, bombers, military exercises) are stated in the agreement text. Any information gathered that does not specifically conform to the letter and spirit of the text is collateral. In the case of confidence-building regimes, however, this distinction is less clear since the object of observation is undefined. Yet, there will likely remain some degree of consensus—reflected in the selection of airborne platform, sensors, and operational procedures—as to what is expected of the confidence-building overflights and what behavior violates the spirit of the agreement.

For the country conducting a cooperative overflight, collateral information can be a side benefit (obtained passively or actively) of an agreement, providing background information on the agreement, collateral intelligence, warning, or cuing. For the side being overflown, collateral information may be going to a country that may not have the overflown country's best interests at heart. Of course, cooperative aerial surveillance is likely to be reciprocal, so each country will both enjoy the benefits and suffer the loss of collateral information.

Negotiated constraints could limit the compromise of this type of information. These include:

- closing sensitive airspace to overflights;
- permitting flights only at night or at high altitudes;
- restricting sensor and data storage capabilities;
- disallowing storage of data (all monitoring would have to be done by an inspector in real time);
- passing collected information (raw data) through host country preprocessing;[20] and
- employing only UAVs.[21]

Moreover, not all of this information is equally valuable (to the inspecting party or the host country). Each party must weigh its potential informational losses against the gains of the accord and the gains from conducting its own overflights.[22]

Background Information

Background information is that acquired beyond the specific mandate of the agreement, but still useful for achieving its goals. For example, a treaty may call exclusively for the aerial counting of a hypothetical TLI. During the overflight, sensors image the sole production facility for the TLI. Using photogrammetric techniques, the volume of the facility is measured and combined with other clues (e.g., on-hand supplies and storage areas) to estimate its production potential. If this potential correlates with the legal number of TLIs, confidence in the treaty is enhanced; if the figures do not correspond, and there appears to be excess capacity, then the inspecting party would be alerted to the possible presence of covert TLIs.

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[19] Technically, this could be confirmed by navigation equipment alone (as might be necessary at night). However, if the level of animosity is high (and thus the stakes as well), the observers may want to see for themselves that the aircraft is on course.

[20] Preprocessing might involve the manual expurgation or computer filtration of all material not deemed necessary for the purposes of the agreement.

[21] UAVs are discussed in more detail in ch. 3.

[22] Because the Soviet Union and the United States already enjoy advantages provided by NTM, their informational gains will be relatively small compared to those of other, less advanced countries. (The French SPOT-Image multispectral remote-sensing satellite produces relatively low resolution imagery for international sale.)

Collateral Intelligence

Information collected that is not related to an agreement, but instead covers the gamut of social, economic, political, and military targets is collateral intelligence.[23] This information ranges from the trivial to the vital. Collateral intelligence can provide a clear view of a previously obscure fact or confirm other, unverified facts. One example of collateral intelligence is the collection of imagery of agricultural areas to get a better understanding of annual crop yields and potential shortages. Another example would be photographs of a piece of sensitive military hardware.

Also in the class of collateral intelligence would be all information gained from training sensors on parties not subject to an overflight agreement when flying near their border or during transit over their territory to or from a host country. Transit flights would probably be restricted to commercial air corridors.[24]

Through the collection of intelligence, a nation refines its strategic assessment of another country and acquires a better understanding of the threat it may pose.[25] It is in the national security interest of each country to know the most it can about the others. The paradox is, however, that it is not always in each country's national security interest to share like information about themselves with others. Certainly, the United States has all sorts of sensitive facilities it might not like the Soviets to fly over. On the other hand, U.S. analysts would like to get a peek at comparable Soviet sites.

The conflict between a desire to maximize the intrusiveness of overflights over other countries and the need to minimize this same intrusiveness over one's own country is central to aerial surveillance negotiations. Increased transparency may not always build confidence and good relations. There are two levels of transparency: the macro and the micro. At the macro level, information on force structures, military readiness, and operational practices can indeed add confidence that one power does not pose an immediate threat and perhaps has adopted a more defensive posture (e.g., moving troops away from the border). However, at a lower, micro level, little additional confidence is won by granting more information (e.g., a weapon's design), and perhaps something important is lost to potential adversaries (e.g., knowledge of a weapon's vulnerabilities).

In negotiating an overflight regime, the issue of what the agreement will cost in terms of information lost must be weighed against the benefits.

Aerial Warning

Unlike the other categories of information collection, aerial warning might actually be a specified and negotiated utility of an overflight regime (see above). However, even if aerial warning is not an intended utility, aerial reconnaissance over militarily significant areas might provide warning at the tactical or strategic level.[26]

Aerial surveillance could add to a monitoring regime's ability to reveal a breakout attempt by providing treaty-mandated information and collateral information, which could be synthesized and combined with other sources of information.[27]

Similarly, militarily significant developments that may or may not be restricted by another treaty might also be revealed by overflights negotiated for some unrelated function. For example, aircraft monitoring air pollution levels over large cities might detect the movement of large military formations toward a border.

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[23] Note that what is defined as "collateral intelligence" and what is "background information" is based explicitly and implicitly on the wording of an agreement.

[24] This report does not address the illegal collection of intelligence except to mention that preflight inspections may be necessary to uncover illegal sensors secreted among the legitimate sensors. Illegal efforts could include covert sensors and intentional diversions from an agreed flight profile (e.g., dipping below minimum altitude to enhance sensor resolution beyond legal limits or changing course to document some event off the flight path). The collection of collateral information differs from the illegal collection of intelligence in that collateral information is collected as a byproduct of the overflights and does not violate any law.

[25] The discussion here of information gathering, particularly of collateral intelligence, parallels that developed earlier on confidence building. The difference is that background information, collateral intelligence, warning, and cuing, as defined in this report, are collected outside the provisions and spirit of an accord, while the information gathered for confidence building is countenanced by an accord. The same information might be labeled as confidence building in one regime and collateral information in another.

[26] The U.S. Defense Department defines tactical warning as "a warning after initiation of a threatening or hostile act based on an evaluation of information from all available sources" and strategic warning as "a warning prior to the initiation of a threatening act." (U.S. Joint Chiefs of Staff, *Department of Defense Dictionary of Military and Associated Terms*, Joint Pub. 1-02, Dec. 1, 1989, pp. 350, 363.)

[27] In turn this interaction of information would lead to a more efficient use of available monitoring resources. See ch. 6 for a discussion of how prior information can be used to enhance the utility of overflights.

Overflights might also indirectly indicate the possibility of threatening activities. This would be the case if a party suddenly began to refuse overflights of certain areas or over its territory as a whole. Refusals would alert the observing party to possible mischief, compel it to focus other assets more intently, and, if no satisfactory resolution to the problem is found, respond as if militarily significant activities were occurring.

Furthermore, the inspecting party might use aerial surveillance to disrupt or delay an impending breakout by requesting overflights of critical areas (e.g., forward staging areas for conventional forces) and forcing the host country to conceal this hardware or activity (potentially throwing off its entire breakout schedule), or to expose it prematurely, thus giving the inspecting party time to react.[28]

Cuing[29]

As with collateral intelligence gathering, the potential role for aerial surveillance in cuing or targeting is controversial. It is arguable that using overflights to direct other systems may go against the spirit of an accord; but some types of cuing can reinforce the main goals of an agreement. This is the case when overflights uncover ambiguous activities or objects that are beyond the airborne sensors' ability to resolve. If the inspecting country did not have any other way of determining the legitimacy of its discovery, the result might be unfounded recriminations or an unanswered threat, thus raising tensions or danger. However, if the location of the discovery could be passed on to human inspectors or NTM, the ambiguity might be easily resolved.

But cuing can also be used in a way that is obviously antithetical to the spirit of most agreements: the same information that can localize an ambiguity for further observation may also be used to target the items being observed (or others not related to an accord) for military attack or covert operations. Target information can be specific, e.g., coordinates of a fixed site; or it can be general, e.g., the operational behavior of mobile systems or groups of forces. Aerial surveillance could also be used to provide accurate tactical maps for military or other purposes. These are further examples of how transparency may not be a wholly beneficial objective.

Aerial Surveillance and Other Means of Observation

The utility of aerial surveillance to gather information in support of an agreement is not unique. Many of its features are shared with NTM and OSI. The selection of which monitoring systems to use, and in what combinations, will be determined by the negotiating parties based on the ability of each measure to detect the desired signatures, the synergistic effects of different sensors, the degree of cooperation possible between parties, the capabilities and capacity of NTM, the political advantages of open cooperation, the intrusiveness of the measure, and financial costs.[30]

Aerial Surveillance and NTM

There is considerable overlap in the potential roles of aerial surveillance and NTM. Both kinds of systems can take imagery from overhead and over wide areas. However, while aerial surveillance as described here is cooperative, NTM is generally unilateral or alliance-based. Cooperative measures can be (and have been) negotiated to enhance NTM capabilities, but the sensors and platforms themselves can operate independently of any agreement.

Among the potential advantages that aerial surveillance holds over at least some NTM assets are greater flexibility, possible real-time physical access to the sensors, direct cooperation between parties,[31] and relative political and technological insensitivity.

An aerial surveillance regime could be negotiated to be more flexible than some NTM, varying flight profiles by timing, ground track, and altitude.[32] As a recent report to the U.S. Defense Department stated,

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[28] For one application of this idea, see James R. Blaker, "On-Site Inspections: The Military Significance of an Arms Control Proposal," *Survival*, vol. 26, May/June 1984, pp. 98-106.

[29] See ch. 6 for a discussion of the value of prior information.

[30] The relative financial costs of aerial surveillance, OSI, and NTM depend heavily on the specific details of a prospective agreement, as well as on the overlap of this agreement with other agreements and national security requirements. This report briefly examines the relative costs of NTM and aerial surveillance for synoptic search in ch. 6, box 6-H.

[31] The limited cooperation between the United States and the Soviet Union on NTM has been confined to facilitating the observation of TLIs through movement freezes, nonconcealment, deliberate exposure, and noninterference.

> The existence and utility of reconnaissance satellites is accepted by both sides. Satellite orbits are highly predictable. It is taken as a given by each side that the other will refrain from some activities, which would otherwise be observable, during a satellite pass—once or a few times per day, say for a total of 20 minutes. The long advance predictability of reconnaissance coverage makes it possible to hide, by careful advance scheduling, even very large and elaborate activities. Each side might worry, in the extreme case, that preparations for war or treaty breakout could be thus hidden.[33]

With a sufficiently narrow preflight notification period making it impossible to conceal a violation of an agreement before a plane might arrive, aerial surveillance might be able to plug gaps in NTM coverage. Airborne platforms might have the flexibility to adjust their flight profiles to optimize sun and sensor look angles, and to change altitude to maximize a sensor's resolution or field of view.[34] Aircraft might also be permitted to fly under cloud cover or loiter over areas of interest.

In addition, overflights could have the advantage, if negotiated, of real-time interaction between the sensors and the inspectors. An inspector manning a sensing device on a plane could maintain, fine-tune, retarget, or change the focal length of the instrument if something interesting caught his or her attention.[35] The inspector could also mark and annotate important sightings to facilitate postflight analysis.[36]

And as mentioned above, because observers are in constant contact with host country escorts, a cooperative atmosphere can be nurtured that is wholly missing from NTM.[37] The confidence that arises from this may lay the foundation for more significant accords. And denial of requested flights could signal a less cooperative relationship, heightening vigilance by other means.

Lastly and perhaps most importantly, information collected by an overt airborne sensor—particularly if parties inspect or share sensors—could more easily be released publicly to confirm compliance, build general confidence, or support charges of noncompliance. Direct release of NTM data is contrary to government policy and is done so only in the most extreme cases. Even in these cases, the evidence of violation displayed is likely to be degraded to avoid giving away information about which system uncovered the violation and how advanced the NTM sensors really are.

The primary advantage of NTM assets is that they are largely independent of political events and negotiations. If an important agreement is abrogated or if surveillance flights are refused, aerial surveillance could leave a country blind to critical developments. NTM would remain unaffected, because it does not usually depend on the cooperation of the country under observation.[38] NTM employment is also not constrained by sensor-limiting compromises, formal notifications, or flight plans. A second advantage of NTM assets is that they can monitor more than one agreement at a time.

Of course, the choice for the United States and the Soviet Union probably will not be between aerial observation and NTM. The questions are more likely to be: what can aerial observation add to current NTM and how can they interact effectively? According to the NATO Open Skies proposal, aerial surveillance is supposed to "complement" NTM.[39]

Besides filling gaps in NTM coverage and capabilities, overflights might be used to cue NTM to particularly interesting sites and to clarify ambiguous NTM information.[40] Overflights or their notification might also be designed to trigger activity that

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[32] On the other hand, negotiators might agree to limitations and restrictions on overflights that would make them relatively less flexible.

[33] S. Drell et al., *Verification Technology: Unclassified Version,* JASON Report, r89-100-11, The MITRE Corp., McLean, VA, Mar. 7, 1990, p. 131.

[34] "Open Skies Aircraft: A Review of Sensor Suite Considerations," The MITRE Corp., Bedford, MA, unpublished manuscript.

[35] Ibid.

[36] On the other hand, escorts would be looking over the inspector's shoulder and could thus get an idea of what the inspector thought important. This information could be useful in refining concealment techniques.

[37] On the other hand, close contact has the potential for turning into friction should relations take a turn for the worse.

[38] As mentioned above, the United States and the Soviet Union have negotiated some cooperative measures that assist NTM.

[39] See app. D.

[40] See ch. 6.

Box 2-B—Aerial Surveillance for Countries Without Advanced NTM

Until fairly recently, countries with little or no NTM have had to rely on the generosity of the superpowers for a detailed view of the world, including information about the compliance of their neighbors with international agreements. The superpowers' monopoly on advanced NTM limited the quality, quantity, and timeliness of NTM information available to third parties. Yet increasingly, countries have other options: participation in consortia to develop independent NTM or the purchase of commercial imagery from other countries. France, Italy, and Spain are investing in the *Helios* military reconnaissance satellite system to be operational in early 1994. The United States, France, and the Soviet Union sell relatively low-grade satellite imagery. In the future, international organizations might pool national resources to deploy reconnaissance satellites to monitor agreements or increase global transparency.

Cooperative aerial surveillance might also be used to fulfill the informational need of some countries. With the negotiation of mutual overflights, these countries would at last obtain an independent source of compliance observation and confidence building. If the cost of an aerial surveillance regime remained beyond their reach, they might spread the cost among like-minded countries by maintaining a fleet of common aircraft or by promoting aerial surveillance by international organizations. If they are willing to negotiate the use of an advanced airborne sensor suite, they might even eventually narrow the current informational gap between themselves and the superpowers. This capability will still be limited to overflights of participating states, so participants would still lack the NTM owners' ability to monitor the territory of potential adversaries without their consent.

Granting foreign countries the right to overfly U.S. territory has important implications for the U.S. Government. Such overflights will, to a certain extent, level the informational balance between these countries and the United States, ending an American advantage over all countries except the Soviet Union. How important this leveling is must be determined by U.S. policymakers. It may be the necessary price to get other countries to sign on to important treaties that had traditionally been left to the superpowers to verify. It may also be the price of a more open world. (See table 4-2 in chapter 4 for a listing of the asymmetric advantages and disadvantages of countries negotiating Open Skies.)

would be detectable by NTM. For example, NTM might be able to spot a large mobile TLI during its transit from an area to be overflown to shelter elsewhere. In some areas, aerial surveillance might even be used to free up NTM assets for other targets. (See box 2-B.)

Aerial Surveillance and OSI[41]

Unlike NTM or aerial surveillance, an OSI is an inherently close-up, but local, affair. OSIs, like aerial surveillance, are also cooperative measures, requiring the consent of the inspected state. On-site inspectors can go places and do things that would be impossible for other monitoring systems. For example, only an OSI can take radiation measurements of a warhead from close enough to negate concerns over shielding; only an OSI can examine the interior of a closed-out production facility. Yet on-site inspectors are limited in the territory they can cover during a given inspection. A similarity between aerial surveillance and OSI, not shared with NTM, is that they both take place inside the earth's atmosphere and thus can both take part in air sampling. All forms of monitoring, with the right technology, could take pictures and read identifying tags on TLIs.

It is in the areas where aerial surveillance and OSI are dissimilar that they may work best interactively. At a minimum, OSI can cover the declared inspection sites, while aerial surveillance flights (and NTM) survey the potentially vast territory not subject to inspection. If ambiguous or suspicious activities or objects are detected during these flights, an inspection team might be sent to visit the site, perhaps while the aircraft loiters overhead.[42] A broad aerial search could trigger a more time-consuming, but more precise, inspection. Conversely, overflights might be used to examine several inspectable sites at a time, both to prioritize subse-

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[41] For a discussion of on-site inspection types, benefits, and costs, see U.S. Congress, Office of Technology Assessment, *Verification Technologies: Measures for Monitoring Compliance With the START Treaty—Summary*, OTA-ISC-479 (Washington, DC: U.S.Government Printing Office, December 1990).

[42] This is provided that the site is on a negotiated list of inspectable sites or the treaty allows for suspect-site or invitational inspections.

Box 2-C—Reading Tags From Aircraft

Tags on treaty-limited items (TLIs) have been suggested as a method for identifying and counting legal TLIs and for making it more difficult for a potential treaty violator to intersperse illegal TLIs among legal TLIs.[1] Tags that might be read from an aircraft are of three basic types: 1) self-powered tags that send a signal to a receiver on the aircraft; 2) tags that are powered by an interrogation signal from the aircraft and respond; and 3) tags that are powered by the host country at the time of overflight.

Reading tags remotely has been a controversial issue, because of a fear that the tag could be used to militarily target the tagged TLI in a crisis. Although it might be possible to design a tag incapable of being used for this purpose, the somewhat irrational fear of compromising legal TLIs remains, making negotiations difficult.

The first and second types of tag bring out targeting concerns the most often. It is argued that during a crisis these tags could be read (either by a direct signal[2] or an illumination-induced signal) and their corresponding TLI targeted. One relatively simple solution would be to provide each local commander with a hammer to destroy the tags early in a crisis. However, while this solution may lower the potential for direct targeting, it does not address the possibility that operational analysis of the tagged TLIs' positions would, over time, provide general targeting information and movement predictability.[3]

The potential for targeting TLI through the operational analysis of tag reading data also applies to tags that are incapable of transmitting without an attached power source under the control of the host country. However, these tags leave less room for misuse of the tags. They could not be covertly interrogated for position information. With this third type of remote tag, when an overflight begins, the host country activates all of its tags so that they can be read from the plane. TLIs not transmitting or responding with invalid information would be considered violations. After the exercise the power supplies would be switched off.

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[1] This task can be particularly important if look-alike objects are both covered by a treaty and also outside its jurisdiction. For example, the Conventional Armed Forces in Europe Treaty does not cover Soviet naval equipment that is physically indistinguishable from its army counterpart which is restricted.

[2] Some argue that the signal power of an active tag could be set low enough so that only planes at very low altitude (and thus only cooperatively) could read them. However, the example of the extremely low-powered Voyager II spacecraft transmissions being picked up at interplanetary distances casts doubt in some minds about the effectiveness of such power restrictions. Another suggestion is that infrared tags be used which could be shielded against pulsed infrared detection. Likewise, some shielding might be made for the other types of tags as well. These suggestions are really variations of the third category of tags: those that can essentially be turned off except during overflights.

[3] This is true for any monitoring mechanism that examines deployed TLIs.

quent inspector visits and to avoid using up a ground inspection quota on obviously compliant locations.

Further in the future, overflights and inspections might be combined in a kind of "SWAT team" approach. A long-range helicopter loaded with inspectors and escorts would fly over the host country searching for suspect TLIs. Upon seeing a TLI, the helicopter would have the option to land and conduct a ground inspection (e.g., a tag reading). The helicopter would then continue its flight, stopping for further inspections, perhaps according to a set quota. Another unconventional idea would be to have aerostats anchored at perimeter portal monitoring sites as a kind of floating perimeter control.[43] Sensors on the balloon would detect the movement of TLIs into or out of the monitored site.

Aerial surveillance does have some advantages over OSI. Overflights could be used to examine sites considered too militarily sensitive to allow inspections. And because of their ability to cover large amounts of territory quickly, overflights could be used to read tags remotely on large numbers of far-flung TLIs (see box 2-C).

Overlapping Agreements and Assets

Current international agreements and security concerns already require U.S. surveillance of most of the world's land masses. This surveillance is mainly in the form of NTM, but includes cooperative arrangements such as OSIs. Future agreements will probably mean more intensive and extensive coverage. Examining each prospective agreement separate from others that cover much the same ter-

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[43] Radar-equipped aerostats are currently used along the U.S.-Mexican border to monitor the illegal entry of aircraft into U.S. airspace. Concerns over operations in severe weather would need to be addressed.

Photo credit: U.S. Air Force by M. Sgt. Ken Hammond

Warsaw Pact observers and their NATO hosts disembark from a German Army CH53 helicopter during the 1987 Reforger Exercise held in then-West Germany. In the future, inspection "SWAT" teams might combine the best aspects of aerial surveillance and OSIs.

ritory may result in an inefficient and costly allocation of surveillance assets as well as a duplication of support and organizational resources. This is particularly true for Europe, where a series of overlapping agreements are in force with several others under negotiation. For example, an aerial surveillance agreement covering a small region may be relatively cost-effective when compared to a new photo reconnaissance satellite, but the same satellite might be able to adequately monitor several other treaties as well at a lower net cost.[44] The executive branch and the Congress need to consider how different verification regimes might interact.

Conclusion

Whether an agreement is intended primarily to foster good will, watch over a tense border, prepare for an OSI, or search for illegal weapons, aerial surveillance may be able to play a role. It can be the central mechanism of an accord or one provision among many, performing only those functions it can do most effectively and cheaply. Through the collection of collateral information, it can also lend additional support to treaty monitoring, hone our assessments of our adversaries, and warn of threatening activities. The decision to include provisions for aerial surveillance in an accord should result from an assessment of the suitability of overflights for the task at hand, the unique qualities of the different monitoring options, the potential for synergism with NTM and OSI, and possible interactions with other verification regimes. Finally, the ideal verification package will have to be weighed against financial and intelligence costs, as well as negotiability.

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[44] See box 6-H in ch. 6 for some rough cost estimates.

Chapter 3

AIRBORNE PLATFORMS AND SENSORS

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Chapter 3

AIRBORNE PLATFORMS AND SENSORS

Summary

This chapter surveys some of the types of airborne platforms and sensors that might be appropriate for agreed overflights and examines major issues for each. It also discusses how negotiations on operational issues can affect the success of an aerial surveillance regime.

The type of airplane or helicopter used in overflights must meet requirements for range, sensor payload, passenger room, safety, reliability, and negotiability. More exotic aerial surveillance regimes might use unmanned aerial vehicles (UAVs) or lighter-than-air craft.

A wide variety of imaging sensors, spanning the electromagnetic spectrum, could be employed during a cooperative overflight. Air samplers or sniffers and radiation detectors could be used to detect restricted chemical and radiological emissions. Signals intelligence (SIGINT) collection, passive acoustic devices, and magnetic anomaly detectors (MAD) might also be used to ferret out information. Sensors can be combined to provide 24-hour, all-weather effectiveness and to complicate attempts at concealing treaty-limited items (TLIs).

Operational considerations are also important. The number of flights relative to the area and composition of the overflown territory, the frequency and duration of overflights, and the amount of advance notice given must be appropriately matched to surveillance goals.

Introduction

Cooperative aerial surveillance involves flying one or more sensing devices (a sensor suite) over the territories of the signatories of an agreement. The platform flown could be an airplane or helicopter, but a case might be made for other craft, e.g., UAVs and lighter-than-air craft. The sensors carried might simply be the eyes of a human observer or more sophisticated cameras, signal gatherers, or air samplers.

The aerial platforms and sensors should be suited to their missions as defined by the overflight agreement. At the same time, the choice of platforms and sensors will likely be limited, primarily for reasons of cost and intrusiveness, to the minimum configuration needed to accomplish the goals of the accord. In the case of some potential agreements, e.g., Open Skies, the goals might be so broadly defined that no minimum configuration is readily apparent. However, in a regime meant to sample the pollutants near designated powerplants, loading a plane with SIGINT equipment would be clearly unnecessary. Similarly, operational criteria should be appropriate for the flights. If the agreement being negotiated calls for short-notice monitoring of some easily relocated TLIs, a prearrival notification period of 48 hours may render the overflights irrelevant. Likewise, an accord that allows the monitoring of troop movements might be undermined by territorial restrictions on overflights.

Airborne Platforms

Types of Platforms

Airplanes

Airplanes are especially useful for missions that require fast air speed, long durations, large sensor payloads, or film changing and sensor maintenance in flight. A wide variety of civil and military

Photo credit: U.S. Navy contractor, released by Department of Defense

The P-3C Orion, a maritime patrol version of the Lockheed Electra, began service in the U.S. Navy in 1969 and has since found its way to many other countries. Its 10-person crew employ a variety of sensors to detect submarines. Note the magnetic anomaly detector protruding from the tail.

U.S. AIR FORCE

Photo credit: U.S. Air Force

Helicopters might prove useful in agreements that seek to combine aerial surveillance and on-site inspections.

airplanes have already been modified for surveillance activities—from sophisticated spy planes, like the TR-1 (descendant of the U-2), to transports, like the C-130. Even a two-seat, civil aircraft could be modified to play some role. Most agreements would probably require at least one representative of the overflown country to be on the plane as an escort, if not as the pilot and sensor operator.[1]

Helicopters

Provisions of the 1990 Vienna Document[2] permit observers in host-country helicopters in Europe to monitor large-scale conventional military activities. Generally of more limited speed and range than airplanes, helicopters might be particularly useful for missions exploiting their relative strengths: low-level flying, slow flying and temporary hovering, and close-quarter landing. Helicopters, like airplanes, could allow sensors to be adjusted or reloaded with film during flight.

Photo credit: U.S. Department of Defense

The AV-8B Harrier jump jet (top) and the developmental V-22 Osprey tilt-rotor aircraft (bottom) are examples of platforms that share features of both airplanes and helicopters.

Low-altitude flights would enable sensors to probe beneath all but the lowest cloud cover or fog. This might mitigate the need, in the daytime at least, for sensors more sophisticated than human vision or conventional photography. It might also improve the utility of sensors that need to get close to their targets to work efficiently (e.g., MADs). (But note that lowering altitude reduces the amount of territory visible to the sensors on board.)[3]

Similarly, slow flying[4] or hovering over a potential target or a declared site might permit more sensitive instrument readings. It would also give the inspectors time to examine a suspicious object from a variety of altitudes, look angles, and sun angles.

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[1] Although most scenarios include both inspecting and host country representatives on a plane, either party might be granted sole overflight authority.

[2] This product of the Conference on Security and Cooperation in Europe provides for aerial and ground observation of military exercises above a certain size.

[3] The line-of-sight to the horizon varies as the square root of the sensor height. For a helicopter flying at an altitude of 1 mile, the line-of-sight to the horizon is approximately 90 miles. For the same helicopter at an altitude of 1/4 mile, the distance to the horizon is approximately 45 miles.

[4] Slow air speeds (about 30 knots) minimize photographic image blurring and platform vibration. Higher speeds and hovering increase vibration. As cited in Allen V. Banner, Andrew J. Young, and Keith W. Hall, *Aerial Reconnaissance for Verification of Arms Limitation Agreements: An Introduction* (New York, NY: United Nations, 1990), p. 139. Maintaining minimal vibration may not be as important as hovering for some types of sensors.

Unlike most airplanes, a helicopter, however, can land without an airstrip. This enables a helicopter to combine the role of aerial monitor and on-site inspector. A sensor-bearing helicopter could detect an anomaly from the air and then land with inspectors who could document any violation.[5] All other modes of reconnaissance require that the sensor collect unambiguous evidence of violation directly (necessitating a more refined sensor) or that it cue other means of collecting evidence, such as ground-based, suspect-site inspection.[6]

Unmanned Aerial Vehicles

UAVs include "remotely piloted vehicles (RPVs), which require remote control by human pilots; autonomous aircraft (drones), which do not; and aerial vehicles which permit, but do not require, remote control by human pilots."[7] UAVs may resemble either an airplane or a helicopter: some fly in a straight path, while others can hover. Most UAVs are small and have relatively short range; however, Boeing's recently demonstrated Condor can stay aloft above 65,000 feet for several days.[8] Because these aircraft are unmanned, there is no one on board to maintain sensors, reload film, or look out in a direction where the sensor is not pointing. At most, a human controller on the ground might be able to redirect and focus the sensors on board in real time. These characteristics make UAVs an attractive alternative to other platforms, because the potential for collateral information gathering can be reduced to an absolute minimum. Only that which is recorded by the sensors on the UAV or seen on a remote monitor is revealed to the inspectors on the ground. This information can be readily restricted by mechanical adjustment of the sensors. Covert sensors would also be difficult to hide on the relatively small vehicles.[9] Lastly, UAVs could monitor events that might be hazardous to human observers (e.g., chemical leaks and nuclear test venting).[10]

Photo credit: U.S. Department of Defense

UAVs, equipped with television or forward-looking infrared sensors, collected reconnaissance and targeting information during Operation Desert Storm.

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[5] Such landings would likely be subject to some numerical or time quota to lessen their intrusiveness and cost, as well as to safety constraints.

[6] Helicopters could also be employed to land a quick-response team that would ring a suspect facility with rapidly deployable perimeter sensors to ensure that no mobile TLI escaped the facility while it was being prepared for an internal suspect-site inspection. Note that this is not specifically an aerial surveillance task. The preparations required at a sensitive site can be quite extensive and time consuming. If the preparations were not allowed, the site might not be included in the accord for reasons of national security. A discussion of the trade-offs in on-site inspection systems can be found in U.S. Congress, Office of Technology Assessment, *Verification Technologies: Measures for Monitoring Compliance With the START Treaty—Summary*, OTA-ISC-479 (Washington, DC: U.S. Government Printing Office, December 1990).

[7] U.S. Congress, Office of Technology Assessment, *New Technology for NATO: Implementing Follow-On Forces Attack*, OTA-ISC-309 (Washington, DC: U.S. Government Printing Office, June 1987), p. 230.

[8] Breck W. Henderson, "Boeing Condor Raises UAV Performance Levels," *Aviation Week and Space Technology*, Apr. 23, 1990, pp. 36-38.

[9] Many aircraft, other than current UAVs, could be converted for remote operation.

[10] Amy Smithson and Michael Krepon, "Strengthening the Chemical Weapons Convention Through Aerial Monitoring," Occasional Paper #4, The Henry L. Stimson Center, Washington, DC, April 1991, p. 26.

Photo credit: Westinghouse Airships, Inc.

Westinghouse Sentinel airship with its ground crew. Airships normally operate at 10,000 to 15,000 feet and at speeds in the tens of knots.

Lighter-Than-Air Craft

Dirigibles, balloons,[11] airships, aerostats, and blimps may be uniquely attractive for some purposes. Floating aerial platforms have the advantages of sensor stability (extremely low vibration), relative background silence for acoustic sensors, unrestricted access to sensors (on crewed craft), large payload capacity, endurance, and extended hovering.[12] The last attribute could enable tethered aerostats to provide an airborne sensor perimeter around a site (e.g., rocket motor plant) either for the term of an agreement or until preparations for an OSI were completed.

During the 1989 celebration of the French bicentennial, Paris police, stationed aboard a blimp, kept almost continuous vigil over the crowds and the comings and goings of world leaders. They professed the ability to identify an individual 1 mile distant.[13]

The chief disadvantages of these platforms are their slow air speed and vulnerability to severe storms. In particular, they would not be a good choice for searching for easily moved and hidden objects or for covering large areas of territory in a relatively short time.

Platform Issues

Aerial platform issues include: whose aircraft is used, who flies it, how many inspectors and host country escorts are on board, where can it land (refuel), what flight rules apply (perhaps those set by the International Civil Aviation Organization (ICAO)), and what will be the language of air traffic control.

Negotiators will also have to decide whether aircraft will be allowed to loiter over a particular spot, make repeated passes over the same territory, or change its flight plan during the flight (at a minimum, to avoid storm fronts). Moreover, minimum (and possibly maximum) altitudes may need to be codified.

Irregularities will also need to be considered: what if an aircraft crashes, what if the pilot intentionally strays off the mandated course,[14] or what if the plane fails a preflight inspection or safety check?

Overflown nations may be concerned that contraband sensors could be secreted aboard (or even in the skin of) the aircraft. If an accord disallowed a type of sensor or put limits on the capabilities of the agreed sensors, a preflight inspection of the platform and its sensor suite by the host country might be necessary. In all cases, except for some UAVs, this could be a fairly difficult and time-consuming endeavor. The provision of platform and sensor manuals and specifications may speed this process up. If the preflight inspection is too long, it may impinge on the ability of the aircraft to accomplish its mission (e.g., searching for easily relocated, mobile missiles). Keeping the aircraft under guard in the host country or some other agreed location after it had been cleared by inspectors might be one solution to this dilemma, because it would obviate the need to inspect the craft before every flight.[15]

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[11] The French were the first to use balloons for military reconnaissance in 1794. William E. Burrows, *Deep Black: Space Espionage and National Security* (New York, NY: Random House, 1986), p. 28.

[12] Some lighter-than-air craft can also land without a prepared airfield, but unlike helicopters, they usually require the presence of ground crews and a comparatively large clearing.

[13] "The Blimp Is Back," *NOVA*, Public Broadcasting System telecast in Washington, DC, Oct. 30, 1990.

[14] A pilot might be tempted to divert his or her course to get a better look at a suspicious object or activity, or to gather collateral intelligence on some sensitive site in an exclusion zone.

[15] On the other hand, the expense of having aircraft dedicated solely to an overflight regime might be too dear for smaller countries, while relying on aircraft provided by the larger countries might be politically unacceptable. (Private communication from Peter Jones, Contractor, Verification Research Unit, External Affairs and International Trade Canada, Ottawa, Canada, Mar. 25, 1991.)

Box 3-A—Types of Sensors

- **Imaging Sensors**
  - **Human vision**
    - **Unaided**
    - **Binoculars**
    - **Optical transducers (night-vision goggles)**
  - **Aerial photography**
    - **Optical**
    - **Infrared**
    - **Stereoscopic**
    - **Multispectral**
  - **Electro-optical devices**
    - **Electronic still camera**
    - **Television (including low-level-light TV)**
  - **Radar**
    - **Synthetic aperture radar (SAR)**
    - **Conventional radar**
  - **Lidar (laser radar)**
- **Nonimaging Sensors**
  - **Signals intelligence (SIGINT)**
  - **Air sampling and sniffing**
  - **Radiation detection**
  - **Acoustics**
  - **Magnetic anomaly detector (MAD)**

SOURCE: Office of Technology Assessment, 1991.

Sensors

Types of Sensors

Imaging Sensors

Human Vision—Although in many ways outmoded by modern technology, human vision remains a viable means of aerial surveillance. A confidence-building regime of purely symbolic overflights might have little reason for permitting more advanced sensors.

Human eyesight might have application in more rigorous monitoring systems as well. If the objects or activities being observed are suitably large and difficult to conceal, then unaided observations might be sufficient for the purposes of an agreement. Peacekeeping missions along desert borders, aerial inspections of missile silos, and observation of military exercises are examples of agreements where eyesight alone might provide satisfactory confidence. Moreover, human vision might cue other, mechanical sensors. For example, a crew member, having spotted a suspicious object or activity, could order the airplane to diverge slightly from its flight path (agreement provisions permitting) in order to photograph the anomalous object from a more advantageous distance or angle.[16] Likewise, the crew member could alter the sensors' scanning mode from a low resolution, wide-area search setting to a higher resolution mode focused on the object.

Under the proper circumstances, selected human beings can perform remarkable feats of visual detection. During World War II, General (then Lieutenant) Charles Yeager could spot German fighters at a range of 50 miles;[17] astronauts in orbit have sighted terrestrial objects as small as trucks in freak occurrences labeled the "hawkeye effect." Binoculars can extend human vision even further.

The detection capabilities of the human eye vary strongly with the angular size of the target (a function of the diameter of, and the distance from, the target), the size of the region in which it might be found, the contrast between the target and its background, the amount of time for which the detection opportunity lasts, and the level of alertness and training of the observer. The *shape* of the target is less important for detection alone.[18]

Some devices can extend human vision beyond the "visible spectrum" (see figure 3-1). Optical transducers, e.g., night-vision goggles, can enable users to see in the infrared portion of the spectrum. Exploiting the far infrared portion of the spectrum in which objects glow by virtue of their own warmth, infrared goggles allow the wearer to see in the dark.[19] Furthermore, because they depict objects according to their temperature, infrared vision systems also reveal phenomena not normally visible to the human eye, e.g., distinctions between conven-

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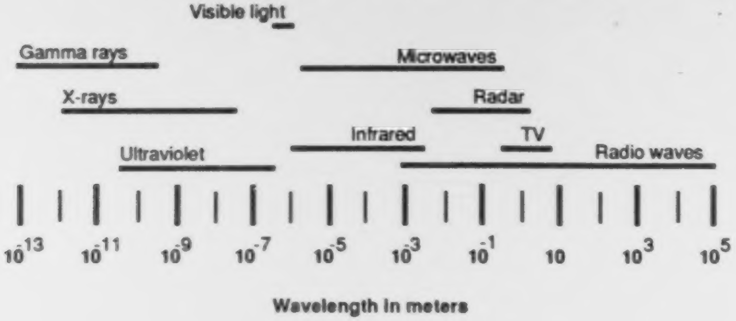
[16] B-2 advocates cite such decisionmaking by bomber crews in search of mobile missile launchers (which are also START TLIs) and other "look-shoot" and "relocatable" targets, though they may have in mind the human use of on-board radar or TV sensor equipment. See General John T. Chain Jr., "A Warrior's Perspective on the B-2," *Armed Forces Journal International*, September 1990, p. 78; and U.S. Senate, Committee on Armed Services, "Threat Assessment; Military Strategy; and Operational Requirements," Mar. 7, 1990, p. 873.

[17] Chuck Yeager and Leo Janos, *Yeager: An Autobiography* (Toronto, Canada: Bantam, July 1985), p. 56.

[18] For more information, including bibliographical references, on this topic, see app. E in Bernard Osgood Koopman, *Search and Screening: General Principles With Historical Applications* (New York, NY: Pergamon Press, 1980).

[19] With some modification, perhaps they could also be worn during the daytime.

Figure 3-1—Partial Electromagnetic Spectrum



SOURCE: Office of Technology Assessment, 1991.

tional camouflage netting and foliage of the same color and pattern; and images of relatively hot objects obscured by foliage, conventional camouflage, smoke, or fog. (Concealment measures that would be more effective are discussed below.) This latter ability to penetrate a leafy canopy would raise confidence that one was not missing TLIs simply because they had been driven into the woods before the aircraft flew over.

In addition, infrared vision systems can in some cases provide a short-term history of an object. For example, residual heat in the engine of a tank or missile transporter, or warm patches of taxiway heated by jet engines, would indicate recent activity that might have been prohibited by movement restrictions (a "freeze") in effect during an overflight or OSI. The heat signatures of overflown facilities might also assist on-site inspectors in deciding where to focus their search effort or reveal covert operations at supposedly closed-out facilities.[20]

For aerial monitoring purposes, it is worth noting that human vision is the one sensor system whose results cannot be recorded for postflight data processing or sharing. Inspectors making visual sightings might take notes or be debriefed after the flight, but they would lack concrete evidence of any wrongdoing.[21] Moreover, the human failing of boredom sets in quickly during a search for sparsely distributed targets, greatly degrading the searchers' effectiveness.[22]

Aerial Photography—Military aerial photography predates the airplane. In fact, placing photographers in intelligence balloons during the U.S. Civil War was considered, though never carried through.[23] It was not until the Spanish-American War that aerial photography first made its military debut in the form of a camera carried aloft by American kites.[24] Since that time, aerial photography has found a wide range of useful applications from strategic reconnaissance by supersecret spy planes to the documentation of local agricultural crops.

A variety of considerations bears on the quality of an aerial photograph. Of these, "resolution" is the most commonly cited parameter, though the ability of a camera to see in more than one part of the spectrum, or to create stereoscopic (three-dimensional) images, can also be important. Stereoscopic imagery aids in the interpretation of photographic reconnaissance data, discussed in appendix B.

Cameras carried aboard aircraft offer a great deal of freedom, affording views at a variety of altitudes, look angles, and sun angles.

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[20] Infrared information about a site's operations might also be compared to the facility's material flow records (obtained through data exchanges) in order to uncover inconsistencies. Smithson and Krepon, op. cit., footnote 10, pp. 15, 23-24.

[21] Unambiguous visual sightings would probably provide sufficient grounds for the overflying nation to take unilateral countermeasures, even if violations could not be "proved" to the other parties of an accord.

[22] In the case of World War II airborne radar search for surfaced U-boats, analysis of sighting data showed that operator fatigue caused a marked decrease in sighting efficiency after only a half an hour. C.H. Waddington, *O.R. in World War 2* (London, England: Paul Elek (Scientific Books) Ltd., 1973), pp. 138-139.

[23] Thomas Crouch, *The Eagle Aloft* (Washington, DC: Smithsonian Institution Press, 1983), pp. 340-341.

[24] The first American noncombat photographs were taken from a balloon in 1860. See Burrows, op. cit., footnote 11, pp. 29-31.

Spectrum—The advantages of seeing in the infrared, as opposed to the visible, part of the spectrum have already been mentioned above in the section on human vision. The most obvious disadvantage—fundamentally lower resolution[25] owing to the use of longer wavelengths of light—can be compensated for by a relatively lower sensing altitude, agreement permitting. One aircraft vendor's concept of aerial search operations includes infrared sensors, but specifies that they would be used during low-altitude segments (5,000 feet, lower than some regimes might permit) of the flight. At such an altitude, the ''swath width''[26] of a notional infrared sensor is given as 5 kilometers, or 3 miles.[27]

Resolution—Resolution is often taken to be ''ground resolution,'' the distance by which two objects on the ground must be separated in order to be distinguishable in a picture; this quantity depends on the altitude of the camera as well as its optical characteristics.[28] (This distance is often about twice the minimum size necessary for an object to appear at all.) More fundamentally, a camera's film has a resolution, ultimately determined by the grain of its emulsion. The ideal camera would project, in a distortion-free way, the image of the ground onto the image plane, where it would be captured. Actual cameras depart from the ideal and degrade resolution to a level somewhat below that which would be expected on the basis of the film alone.[29] As in the case of the human retina, the resolving power of the film depends on the contrast ratio between the target and the surrounding background.

Estimates of the ground resolution needed for various purposes differ from source to source. One commonly cited source[30] draws distinctions between the ground resolutions needed for detection, recognition, identification, and analysis. ''Detection'' refers to noting that the object is present at all; ''recognition'' to determining that it is a missile, vehicle, missile site, or aircraft; ''identification'' to determining what type of missile, vehicle, missile site, or aircraft it is; and ''analysis'' to the performing of detailed technical analysis based upon the image at hand. Table 3-1 shows values for selected agreement-relevant items.

Another source[31] provides a nearly identical list of items and five levels of interpretation—detection, general identification, precise identification, description, and technical intelligence. Not surprisingly, the addition of a less exacting category widens the range of identifiably useful ground resolutions. A submarine, for example, can be ''detected,'' in the sense used by the latter source, given only a resolution of 100 feet (v. 25 feet).

A third source adduces digitized examples to show a tank at the picture element sizes (picture element, or pixel, sizes correspond closely to resolutions) at which it can be identified as an artifact, as a tank, and as a Soviet T-62. These resolutions appear to be approximately 16, 6, and 3 inches, respectively.[32] Note the lack of close agreement with those values cited for a vehicle in table 3-1, typical of the way parameter estimates vary in this field.

A fourth source[33] introduces the Imagery Interpretability Rating Scale (IIRS) which is not based on resolution. Using subjective criteria, the IIRS sets up eight separate slots (labeled rating categories 1 through 8) into which targets are placed according to the aforementioned detection, recognition, identification, and analysis paradigm.

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[25] A concept treated at length below.

[26] Theoretical sweep width, in our terminology; see ch. 6.

[27] John King, ''Airborne Remote Sensing for Open Skies: The Platform,'' in *Open Skies: Technical, Organizational, Operational, Legal, and Political Aspects*, Michael Slack and Heather Chestnutt (eds.) (Toronto, Ontario, Canada: Center for International and Strategic Studies, York University, 1990), p. 29.

[28] The basic expression of the resolution of a camera is its angular resolution, the angle subtended at the camera by two objects on the threshold of appearing as one. ''Ground resolution'' or ''ground sample distance'' is the projection of this angle on the ground. The term ''ground sample distance'' clarifies the point that resolution is an angle inherent in the camera-film combination whereas image interpretation depends upon the size of the ground sample subtending that angle.

[29] Atmospheric effects, such as moisture, pollution, and turbulence, can also degrade theoretically ideal resolution.

[30] ''Minimum Ground Object Sizes for Imagery Interpretation,'' ASCC AIR STD 101/8, quoted in the *Reconnaissance Handy Book* (St. Louis, MO: McDonnell Douglas, 1983), p.125.

[31] Jeffrey T. Richelson, *The U.S. Intelligence Community*, 2d. ed. (Cambridge, MA: Ballinger, 1989), p. 161.

[32] David Hafemeister, Joseph Romm, and Kosta Tsipis, ''The Verification of Compliance With Arms-Control Agreements,'' *Scientific American*, vol. 252, No. 3, March 1985, p. 41. The number of shades of gray available in this digital presentation appears to have been either four or eight.

[33] ''Open Skies Aircraft: A Review of Sensor Suite Considerations,'' The MITRE Corp., Bedford, MA, unpublished manuscript.

Table 3-1—Ground Resolution and Targets

Object	Detect (feet)	Recognize (feet)	Identify (inches)	Analyze (inches)
Missile	3	2	6	1.5
Vehicle	5	2	6	1.5
Nuclear weapon	8	5	12	0.5
SSM site	10	5	6	1.5
Aircraft	15	5	6	1.5
Submarine	25	15	6	1.0
Troop units	20	7	24	6.0

SOURCE: "Minimum Ground Object Sizes for Imagery Interpretation," ASCC AIR STD 101/8, quoted in the Reconnaissance Handy Book (St. Louis, MO: McDonnell Douglas, 1983), p.125.

For example, in rating category 5, the lettering on the wings of a large aircraft can be detected; command and control headquarters can be recognized; a tank can be identified as light or medium/heavy; and technical analysis can be made of airfield facilities. Interestingly, some surfaced submarines—though detectable in rating category 1—have sufficiently similar overall dimensions[34] that they can be identified by type only in rating category 6. For example, the Soviet Romeo-class attack submarine can be distinguished from its Whiskey-class predecessor by the presence of a snorkel cowling.

Photographic film can have a resolution of about 1/5000 of an inch[35], so that a 10- by 10-inch picture similar to that produced by the Fairchild KC-1B framing camera[36] could capture a 50,000 by 50,000 field of resolvable units, the equivalent of 25,000 feet (or about 4 nautical miles) square at 6-inch resolution. This very approximate calculation suggests a sweep width of 4 nautical miles if the camera simply points straight down from, in the case of the Fairchild camera, an altitude of about 20,000 feet.

An Itek camera, derived from the Large Format Camera built for the Space Transportation System (the space shuttle) can resolve 1 meter or better from 12,000 meters.[37] From 20,000 feet, this camera could therefore resolve 20 inches or better, with a very wide field of view. The technology embodied in this camera, however, may make it unexportable and thus unusable in some cooperative aerial surveillance regimes.

The amount of search effort available per sortie is determined, in the case of many aircraft, by the amount of film in the camera. The Fairchild camera cited above carries about 400 feet of film, and could thus take almost 500 4- by 4-nautical mile photographs. These photographs could easily be taken in sufficiently rapid succession to cover a swath 4 nautical miles wide and almost 2,000 nautical miles long; the film can advance through the camera at a rate of 3 inches per second, corresponding to 1.2 nautical miles of ground per second and thus almost 10 times faster than would be needed for perfect coverage of the swath. Some amount of overlap between adjacent pictures would be desirable from the standpoint of a photointerpreter. The aerial surveillance mission may differ enough from conventional military reconnaissance in that larger airplanes could be used, permitting the inflight replacement of film.

Electronic Still Camera—Though normally associated with TV-style "moving picture" cameras, electro-optical technology can also be used in a still camera. Some such cameras use a "push broom" technique, in which a linear array of detectors images thin slices of the scene and the motion of the sensor platform laminates these slices into a two-dimensional image. A 1979-vintage aerial device of this type could record a 3-mile-wide swath at a distance of up to 12 miles with enough resolution to allow counting of individual people and discrimination of different models of automobile.[38] More modern devices use staring arrays, making them completely analogous to TV cameras.[39] They can attain ground sample distances comparable to those of film cameras, and record 8 to 12 bits per picture element, enough to express from 256 to 4 million shades of gray.[40]

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[34] The waterline length of a modern submarine is somewhat variable because the hull is pickle-shaped and the length of the exposed portion therefore depends upon the trim.

[35] *Reconnaissance Handy Book*, op. cit., footnote 30, p. 61. Values vary widely from film to film and depend greatly upon the contrast inherent in the scene itself.

[36] Ibid., p. 8. This camera's modest 6-inch focal length places it firmly in the "medium-tech" niche: export restrictions aside, a 72-inch focal length could readily be used instead, affording "the capability to perform extraordinary feats" according to one expert. (Prepared statement of Michael Krepon, President of the Henry L. Stimson Center, Washington, DC, delivered before the Senate Foreign Relations Committee, Mar. 29, 1990.)

[37] "Peaceful Watchdogs," *IEEE Spectrum*, November 1989, p. 31.

The large dynamic range of these systems—larger than that of the human eye[41]—allows post-processors to bring out latent details hidden amid shadows or glare. (Digital postprocessing of some film images can have the same effect, as will be seen in app. B.) Such postprocessing might be done on board the surveillance aircraft, allowing sites of interest to be revisited later in the flight after processing of imagery taken on the first pass.[42]

Television—TV systems for aerial surveillance share some attributes of human vision and others of photographic and electro-optic systems. Like human vision, airborne TV can be analyzed in real time as the plane is flying, allowing for deviations from the flight path to examine interesting targets more closely or from a more advantageous angle.[43] Like photography and electro-optics, its results can also be recorded and it can operate outside the spectrum normally thought of as "visible." (The advantages offered by operating in the infrared portion of the spectrum are discussed above in the section on human vision.)

Whereas the screen of a digital TV system is divided into pixels (picture elements) whose pre-images on the ground readily define the system's resolution in terms of ground sample distance, the resolution of the conventional, analog, scanning TV system found in most homes is somewhat more complicated to determine. Such a TV system builds its image out of parallel lines scanned onto the screen. The spacing of the lines (512 of them in a conventional home set) determines, much like the number of pixels, the screen's resolution in the vertical dimension. The horizontal dimension's resolution is governed by the ability of the system to make intensity changes along a single scanning line, rather than from line to adjacent line as in the vertical dimension. A conventional 512-line TV image is refreshed 30 times per second; from its 4-megahertz input signal it can make 8 million meaningful samples per second, so each line would consist of 508 samples if none were lost to such "overhead expenses" as blank time between each image refreshment.[44] A realistic assessment of such losses could cut the number of samples per line to 400.[45]

As in film photography, the parameter of interest in TV systems is the ground resolution (and the effective ground sample distance), determined by the line spacing of the TV camera and screen. If 6-inch spacing on the ground were the standard required for aerial surveillance, the conventional 512-line home TV screen would depict a patch of ground 256 feet in length and approximately square. Even a substantially improved TV display would thus be a far cry from a film system in terms of the ability to cover ground (25,000 square feet in the film example above) at a given resolution.[46] Even a digital TV with a 1024- by 1024-pixel array, which could approximate the performance obtained by the combination of the human eye and state-of-the-art conventional optics, could do so only over a narrow field of view comparable to that of a submarine periscope.[47]

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[38] Benjamin F. Schemmer, " 'Electronic Cameras' With Instantaneous Ground Read-Out Now Make Real-Time Precision Tactical Targeting Operationally Feasible," *Armed Forces Journal International*, November 1982.

[39] "Communications, Electronics, Scientific Advances Explode," *Signal*, September 1990.

[40] The MITRE Corp., op. cit., footnote 33.

[41] The human eye perceives about a million shades of gray in its photopic (cone-mediated) mode and another million in its scotopic and mixed (rod-mediated and rod-and-cones-together) modes. (See Koopman, op. cit., footnote 18, p. 322.) A periscope device described by Clark and Stevens likewise has a dynamic range of 60 decibels: its brightest bright is a million times brighter than its dimmest dim. (See David Clarke and Eric G. Stevens, "High-Resolution Camera Provides Key to Electronic Periscope," *Sea Technology*, September 1990, p. 65.)

[42] Assuming that the flight protocol permits real-time changes of flight plan or repeated overflights of the same area.

[43] Real-time analysis or redirecting of sensors has the drawback that on-board host country escorts may be able to witness what piques the interest of the inspecting sensor technician, thus enabling the host country to perfect any attempts at camouflage, concealment, or deception (discussed below).

[44] Eight million samples per second divided by 30 images per second and by 512 lines per image yields 508 samples per line.

[45] This description drawn from Albert Rose and Paul K. Weimer, "Physical Limits to the Performance of Imaging Systems," *Physics Today*, September 1989, p. 30.

[46] Low-light-level TV would be able to improve contrast due to haze or twilight. This could compensate to some extent for lower ground resolution.

[47] Clark and Stevens, op. cit., footnote 41, p. 63.

A special-purpose TV system, such as one to be used in aerial surveillance, might outperform the home set described above by a factor of five.

Synthetic Aperture Radar—Radar actively bounces radio waves off targets to determine their location and size. Airborne SARs use the motion of the airplane during the time that the radio pulses are in transit to and from the target to create the effect of having an antenna far larger than the one actually carried. The duration of the transit and the Doppler frequency shift of the returned signal are used to build up an image of the passing terrain. Because the process involves collation of returns and intensive computation, a SAR cannot produce an image in real time like a TV camera. High-end SARs can approach real time, but lesser SARs are often subject to a considerable delay. The resulting image has a somewhat photograph-like appearance and level of detail.

The along-track (azimuth) ground resolution in SAR is ultimately limited by the wavelength of the radar, but in practice the ability to resolve ground targets closely spaced in azimuth is a function of the physical aperture size (i.e., physical antenna size and thus physical antenna beamwidth) and the ability to remove motion-induced phase errors from the data while synthesizing the long virtual aperture. Phase errors are rinsed out through the use of antenna motion compensation and data processing. The crosstrack (range) resolution is limited by the bandwidth of the radar's transmitter/receiver. The ability to resolve ground targets closely spaced in range depends upon an ability to distinguish very precisely the closely spaced times of arrival of the echoes returning from these targets. This time-domain resolution is inversely related to bandwidth, so fine time resolution implies large bandwidths. With a large bandwidth and good data processing, a SAR image may approach the appearance of an aerial photograph. The fully focused SAR can see farther to each side and provide wider coverage than could the photographic system, and without loss of resolution at longer ranges.

Characterizations of SAR resolution vary and often depend upon unstated assumptions as to the quality of the SAR and the height at which the aircraft is flying. The U.S. Air Force cites the ability of the F-15 SAR to see "a car in a driveway."[48] Another source cites a 12-inch ground sample distance for a SAR, but asserts that the difficulty of interpreting SAR images degrades their utility to that of photographs with twice that ground sample distance.[49] A third, writing in a context similar to the film and TV examples above, says that a SAR would have a ground resolution of 20 feet (v. 6 inches).[50]

Yet another source addresses "sensor swath,"[51] citing a width of 25 kilometers (15 miles) for a notional SAR operating from an altitude of 25,000 feet.[52]

SARs contain advanced digital electronics, so they could be especially problematic from the standpoint of technology transfer. One extreme example is the Joint Surveillance Target Attack Radar System (JSTARS) that was created to support military operations by detecting force deployments and movements behind enemy lines, but could in principle be used for aerial monitoring as well. The Boeing 707-mounted system uses 154 computers, amounting to "the equivalent capability of three Cray supercomputers," to support its mission.[53] In addition to causing technology transfer concerns, such high technology could raise fears in the overflown country that the receiver might be illegally gathering signals intelligence (should such collection be banned by the aerial surveillance agreement). A SAR for cooperative aerial surveillance need not be nearly as complex as the JSTARS SAR: removal of moving-target-indicator, battle-management, and near-real-time capabilities could result in a system able to perform necessary aerial search tasks but palatable from the technology-transfer standpoint and incapable of performing illicit tasks.

Conventional Radar—Conventional, as well as synthetic aperture, radars could find an aerial surveillance application. Reportedly, Boeing's Advanced Technology Radar Project has demonstrated a 4.2-mile range for its millimeter wave radar designed expressly for use against relocatable targets, such as the SS-24 and SS-25 mobile missiles. This short range (projected to increase to over 6 miles) allows for a superb ground resolution (for radar) of about 18 inches. Because of the short timeline for attacking a ground target from a low-flying jet, Boeing's system uses automated pattern recognition to identify targets, placing icons, not images, on the user's display. This identification is aided by the automated use of information derived from other on-board sensors.[54] Such a system could be used in aerial monitoring to cue other sensors to focus on suspicious objects.

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[48] Quoted in *Interavia Aerospace Review*, vol. 45, August 1990, p. 649.

[49] The MITRE Corp., op. cit., footnote 33.

[50] "U.S., Soviets Nearer to Aerial Monitoring Deal," *Defense News*, Nov. 27, 1989, pp. 1 et seq.

[51] Corresponding to "theoretical sweep width" as discussed in ch. 6 of this report.

[52] King, op. cit., footnote 27, p. 9.

[53] "Surveillance Aircraft Tests Slated in European Scenario," *Signal*, September 1990.

Radar, in both SAR and conventional variants, is also useful in defeating conventional camouflage and concealment measures. The relatively long wavelengths of radar allow it to pass unimpeded through clouds,[55] smoke, dust, thin foliage, conventional camouflage, and other visual obstructions. Moreover, radar can be used at night, giving the observer a round-the-clock, all-weather capability.

Lidar—Lidar, a laser cognate of radar, is analogous to conventional radar in many respects except that the laser light is of a much shorter wavelength. The shorter wavelength has the benefit of allowing a theoretically higher resolution, but the drawback of being blocked by weather, foliage, and other impediments.

Comparison of Airborne Imaging Systems

Table 3-2 compares the imaging systems considered thus far. Each has its own unique set of traits. In terms of those tabulated, there may seem to be little reason to adopt SAR. However, as discussed later in the sensor issues section, point-by-point comparisons of sensors omit important synergisms obtainable by using more than one sensor at a time.

Nonimaging Sensors

While imaging methods have received the widest attention in discussion of aerial monitoring and aerial reconnaissance in general—and will continue to be our primary focus in the remainder of this study—certain nonimaging means of information collection merit some mention. Two of these, air sampling and the use of acoustic methods, require that the sensor be within the Earth's atmosphere.

Signals Intelligence—SIGINT collects information through the interception of radio waves. In addition to communications and radar signals, airborne receivers might collect electromagnetic emanations from electrical equipment of all kinds.[56] Such receivers would so closely resemble SIGINT collection devices that a ban on SIGINT collection could effectively prohibit their use as well. Because of the large potential for collateral information collection during a SIGINT flight, the inclusion of SIGINT devices in an accord appears at this time to be unlikely. In fact, the only sensor technology that the United States ruled out for Open Skies was SIGINT.

Air Sampling and Sniffing—A variety of air sampling technologies might be applied to a cooperative overflight regime. Through air sampling or sniffing, aircraft could detect trace amounts of telltale chemical signatures of the production—and perhaps storage—of chemical weapons and missile fuels,[57] the venting of radioactive particles and gases from underground nuclear weapon testing, the release of outlawed pollutants, and other treaty-relevant or defense-related activities. The masking of some of these telltale aerosols or gases by legitimate effluents could complicate the matter of monitoring. Likewise, localizing the source of illegal emissions, particularly near a border, may cause difficulties. (See ch. 5 for a discussion of applications of air sampling and sniffing.)

Radiation Detection—Radioactive emissions from illegal tests or facilities in the form of telltale

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[54] Breck W. Henderson, "Boeing Developing Millimeter Wave Radar To Spot Soviet Union's Mobile Missile," *Aviation Week and Space Technology*, Oct. 8, 1990, pp. 55 et seq.

[55] If a treaty allows flights at lower altitudes, cloud cover could often be flown under, thus enabling any sensor to see below the clouds. However, this is not always the case and flying low results in a narrower swath width.

[56] For example, concern existed that the "racetrack" deceptive basing of the Peacekeeper missile (then known as MX) could be compromised by the detection of electromagnetic emanations resulting from transient loads on its power supply. U.S. Congress, Office of Technology Assessment, *MX Missile Basing*, OTA-ISC-140 (Washington, DC: U.S. Government Printing Office, September 1981), p. 37.

[57] Ibid., p. 36. Concern existed that the "racetrack" deceptive basing of the Peacekeeper missile (then known as MX) could be compromised by the chemical detection of airborne emanations from its fuel.

Table 3-2—Comparison of Airborne Imaging Systems

System	Real time	3-dimensional	Record	Color	Night	Resolution
Vision	Yes	Some	No	Yes	Infrared	Medium
Photo	No	Yes	Yes	Maybe	Infrared	High
Electro-optical still	Maybe	Yes	Yes	Maybe	Infrared	High
TV	Yes	No	Yes	Maybe	Infrared	Low
Synthetic aperture radar	Almost	Yes[a]	Yes	No	Yes	High
Radar	Yes	Yes	Yes	No	Yes	Low
Lidar	Yes	Yes	Yes	No	Yes	High

[a] Phase information allows recovery of a 3-dimensional image.
SOURCE: Office of Technology Assessment, 1991.

neutrons or gamma-rays might also be measured from aircraft carrying detectors. Lighter-than-air craft and helicopters might be particularly useful platforms for these sensors because of their ability to hover for more precise readings. Using these systems for uncovering small radioactive sources, e.g., nuclear weapons, however, may be seriously undermined by shielding and background radiation.

Acoustics—Though usually thought of in a submarine context, passive acoustic detectors can be used in the atmosphere instead of in the ocean. Development work has been pursued in this area.[58] Acoustic detection could be useful in special aerial monitoring tasks where a signature noise could be positively correlated with a monitored item. For example, concern existed that the location of the mobile Peacekeeper might be revealed by the sound of its cooling fans.[59] Of course, in this scenario, observers must be confident that the signature sound cannot be muted or altered to avoid detection.

Magnetic Anomaly Detector—Another sensor technology usually associated with submarines, MADs are designed to detect the presence of large ferrous objects by the size of their magnetic field relative to the background. Because detection of this field follows the inverse cube rule, the detector must get very close to find an object. It has been stated that a submarine can be discovered by an airborne (airplane or helicopter) MAD at about 1,000 yards.[60] Other possible TLIs that might be considered for MAD detection (e.g., mobile missile transporters and trains) are much smaller than submarines and would require higher sensitivities or closer proximity. The latter makes it more likely that helicopters would be the platform of choice.

Sensor Issues

If an aerial sensor suite is to be more than symbolic, it must be able to detect or characterize its target reliably. To do this, its users need to consider the possibility that an overflown country may try to undermine the effectiveness of the sensor system through camouflage, concealment, or deception. Participating states should also assess the intelligence (and perhaps proprietary) costs of having similar sensors fly over their own sensitive facilities. Finally, the United States, in particular, has to decide whether a specific accord requires and is worth the technology-transfer cost of sharing advanced sensors.[61]

Target Characteristics

Effective aerial monitoring necessitates that the objects of attention be observable, either directly or indirectly, by the mutually agreed-on sensor package. For imaging systems this means that the observed item or activity must be resolvable enough to be detected, recognized, identified, or analyzed according to the goals of the accord. For example, a treaty that called for directly counting battle tanks would not be adequately served by a camera with a resolution too poor to distinguish a tank from a truck. Secondary characteristics, e.g., the formation of the tank-like objects, might, however, provide indirect evidence to support the treaty goals.

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[58] The MITRE Corp., op. cit., footnote 33.

[59] U.S. Congress, Office of Technology Assessment, op. cit., footnote 56, p. 36.

[60] Kosta Tsipis, *Arsenal* (New York, NY: Simon & Schuster, 1983), p. 233.

[61] Some experts have stated that future accords might be worded with enough flexibility to allow for alterations or upgrades of the sensor suite as conditions change, technologies advance, or the parties become more comfortable with the regime. However, leaving the specifications of the sensor array deliberately vague or adopting standards that are currently inadequate with hopes of later adjustment may result in tensions (and possibly danger if the omitted sensors are needed for effective monitoring) if subsequent negotiations block any positive changes.

Nonimaging systems must also be selected with their target in mind. Insensitive chemical sniffers might pass over a tightly sealed, covert missile production plant. And SIGINT might yield no clues to the presence of covert facilities that practice strict emission control.

Moreover, looking at the target alone is not enough. The observed object must be put into context. (Remember that resolution is only one factor aiding detection: contrast is important too.) Acoustic and MAD sensors might be overwhelmed by background signatures if their targets were located in an urban area. The object's operating environment and habits need to be examined. Is it important to be able to monitor the object at night or in bad weather? Clearly, the smaller, more mobile, and less emissive an object is, the more difficult it will be for sensors to locate. If all these target characteristics have not been studied in advance of the sensor decision, and the sensor-target relationship not adjusted to the goals of the agreement, the monitoring system could be irrelevant (and indeed misleading).

False Alarm Rate

To the degree that sensors are to build confidence both internationally and domestically, the reliability of sensors becomes a critical issue. If a sensor detects targets that are not there, tensions could be raised for no good reason: one side would think it had detected a violation, the other would react to being falsely accused. In addition, if sensors are used to cue on-site inspectors, false alarms could quickly eat into that country's inspection quota (if there is one).

Camouflage, Concealment, and Deception[62]

Another critical issue for the sensor package decisions is the possibility of an observed party attempting to defeat the airborne sensors by camouflage, concealment and deception:

> Persuasiveness in camouflage consists of suiting the camouflage to the situation and of giving the enemy an impression of reality and probability. For example, when concealing objectives, it is necessary to make them blend in with the terrain or with typical local objects that do not attract attention. False objects should be created in those places where they fit into the setting; they must be similar enough to actual objectives not only in appearance but also in activity.[63]

Photo credit: U.S. Department of Defense

Camouflage net shields M1A1 Abrams Tank from overhead observation during Operation Desert Storm. Such operational camouflage measures would not necessarily be banned by arms control agreements.

If a party's primary motivation for countering surveillance is to proliferate restricted TLIs, it might resort to camouflaging and concealing those TLIs above an agreed ceiling. Camouflage could consist of covering the TLI with leaves and branches cut from a tree, variegated four-color paint, or a camouflage net. Concealment could entail removing the TLI from view by moving it under the cover of another object (e.g., a shelter or the tree canopy) or masking it with fog-like smoke. As mentioned above, some sensors can see through conventional camouflage and concealment measures. However, the manufacturers of camouflage and smoke have been busy creating new and improved products that are designed not only to obscure objects at visible wavelengths, but also at infrared, radio, and ultraviolet.[64]

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[62] For some historical examples of CCD, see app. B.

[63] *Camouflage: A Soviet View*, Soviet Military Thought, no. 22, translated and published under the auspices of the U.S. Air Force (Washington, DC: U.S. Government Printing Office, 1989), p. 180.

Another objective of the cheating party might be deception. By applying deception in the form of decoys—of a TLI itself[65] or of the objects that one would expect to find near a TLI (i.e., an indirect indicator of the TLI)—this party could: 1) divert monitoring assets from true covert activities occurring elsewhere, 2) present a picture of compliance while preparing to break out of the agreement (e.g., the movement of troops out of a designated deployment area and toward the border), 3) dilute OSI quotas by sending inspectors on wild goose chases, and 4) undermine confidence in the reliability of the sensor suite (perhaps as a precedent should a real violation be discovered).

A final complicating factor is that some potential TLIs rely on CCD to survive in a conflict. These TLIs may be exempted from prohibitions on using normal CCD techniques, as is the case for TLIs in the Conventional Armed Forces in Europe (CFE) Treaty.[66]

Multiple Indicators

The best solution to the problem of CCD is to make the job of the violator as difficult as possible, if not impossible. Different imaging systems have different strengths and weaknesses. Configurers of an aerial monitoring aircraft might want to combine complementary imaging systems for a maximum overall probability of achieving the goals of an accord; i.e., detecting the target regardless of countersurveillance measures.

Credible Evidence of a Violation and Data Storage

What happens if a violation of an agreement is discovered? Some would say that this alone would be just cause for abrogating an agreement. However, the history of compliance policy suggests that such black-and-white distinctions are extremely rare. More than one sighting from perhaps more than one source might be required for firm evidence of an intent to cheat.

If the overflight had made no permanent record of the discovery (e.g., visual observation) or the recorded data was ambiguous, the violator could claim that the accusation was a false and political provocation. Inspectors seeking to revisit the site (possibly in a quick-response helicopter) might not arrive in time or might be rebuffed. If a record of the observation were made and the data were clear enough to interpret, the party could credibly argue that the violation spotted was simply an aberration, an accounting error that will be rectified immediately. Therefore, data storage can be important for supporting assertions of noncompliance.

However, stored data can also be a major source of collateral information that the parties might not want revealed. The task is to balance the informational requirements of an agreement against the cost of greater intrusiveness.

Depending to some extent on the sensor, data can be stored in either analog or digital form. In their digital manifestation, the raw data can be more easily processed by computer to bring out important details that might remain hidden in its analog counterpart. This, of course, helps increase the effectiveness of flights; however, it also increases the amount of collateral information lost by the overflown state. For this reason, restrictions might be placed on data storage: it could be limited to analog devices or prohibited entirely. Or, conceivably, the raw data could be passed through a computer program that filters out detail beyond that required by the accord. Lastly, the data gathered could be shared amongst all parties, even to the point of joint analysis.[67]

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[64] Newly recolored, ultralight camouflage nets ordered for Operation Desert Shield (subsequently, Operation Desert Storm) in the Persian Gulf are designed to scatter radar in the 6- to 140-gigahertz range. (''Deployment of Saudi Tan,'' *Jane's Defence Weekly*, Oct. 27, 1990, p. 805.) One company's camouflage netting—laced with metallic dipoles—reflects, scatters, and polarizes radar signals so that the returns approximate the background. It can also be given a foliage appearance or match the background in the near infrared. (''Camouflage Systems,'' company brochure, Teledyne Brown Engineering, Huntsville, AL.) See also Banner et al., op. cit., footnote 4, pp. 88-89.

[65] A TLI decoy might consist of another object that closely approximates the original at the sensitivity of the sensors involved (e.g., a milk tanker for a mobile missile transporter or a set of radar corner reflectors). However, a decoy could also be an elaborate imitation that resembles the TLI in every way (visual, infrared, radio)—except that it can be dismantled and stowed before an inspection team arrives. See Teledyne, ibid.; and *Camouflage: A Soviet View*, op. cit., footnote 63, pp. 203-206.

[66] Article XV, paragraph 3.

Sensors Targeting the United States

Aerial overflight agreements cut both ways. If they are effective in ferreting out useful collateral information about another country, they may reveal more information about your own country than you would like. If an agreement permitted sophisticated sensors with capabilities beyond those of NTM, aerial surveillance might undermine U.S. national security by adding considerably to the Soviet Union's (as well as other signatories') knowledge of the American defense and intelligence establishment.[68]

Even if agreed sensors were limited in their capabilities to prevent the collection of this extra information, the overflown country might still be concerned about the presence of covert sensors placed on the aircraft. This concern might be alleviated by preflight inspections of the aircraft.

If the agreed sensor suites were restricted to a capability equal to or below that of NTM, the United States, in particular, and the Soviet Union might have relatively little to gain by overflights beyond confidence building.[69] Instead, their monopoly on information would be broken by granting equivalent overflight rights to countries with limited independent NTM assets.[70]

Technology Transfer

Parties to an aerial surveillance regime might permit access to each others' aircraft and sensors. The primary reason for such access is the fear of the collection of collateral information. Aircraft inspections would verify the legitimacy of allowed sensors or check for covert instruments. In some cases, for reasons of equity as well as security, identical sensor suites might be shared among all the parties. Since many sensing technologies are on the cutting edge of U.S. technology, and since these sensors may have military and intelligence applications that are important for national security,[71] it may be in the interest of the United States not to compromise them by putting them on an aircraft that will be inspected. In these cases, it may be best to rely solely on commercially available devices; in others, however, it may be worthwhile to give up some technical information in exchange for the benefits of an accord.[72] Of course, settling for less capable technology may affect the ability of the sensor to serve the monitoring goals of an accord, and thus its utility. Only in regimes where there are no restrictions on overflight activity and no inspections of aircraft will the United States be likely to use its technology to the fullest.

Operational Concerns

Time: Notification and Duration

If the task is to monitor a region for certain objects or activities, time can be an important operational factor. This is particularly true for TLIs that are easily relocated or hidden. If a TLI can be removed from aerial view before a flight can reach it, then the overflight has questionable utility. (The time it takes to reach a TLI is the sum of the notification/preflight inspection period and the minimum flight time to the target.) If monitoring success does not necessitate reaching a TLI in a short time, then the length of the notification/preflight inspection period is irrelevant.

The duration of the actual flight is also a central issue in that it determines (when combined with air speed) the amount of territory a flight can cover. Except in the case of symbolic flights or flights to specific destinations, the ratio of the territory scanned to the total territory[73] can have an important impact on how confidently one interprets the data gathered.

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[67] Opponents of data sharing argue that revealing this information would aid a potential cheater nation in perfecting its CCD measures.

[68] Conceivably, overflights could reveal proprietary and economic information as well, undermining economic security.

[69] As discussed earlier, even sensors inferior to NTM might provide the superpowers with useful search capabilities, primarily because of the flexibilities of the platforms.

[70] See table 4-2 in ch. 4 for a discussion of some of the regional and national asymmetries of such accords.

[71] As well as the national economy.

[72] This sharing of information implies some loosening of export control legislation.

[73] This might be the entire territory of a party or that part of it where the target in question would likely appear.

Flight Quotas

Similarly, the number and frequency of flight is important to the level of confidence one can invest in a monitoring regime. As will be addressed mathematically in chapter 6, the number of flights, combined with their duration, puts statistical bounds on certain types of monitoring, especially aerial search. Put simply, the more often and longer a country is overflown, the more confident is the observer in making statistically based judgments of compliance. Increasing the frequency of the flights (i.e., shortening the time between flights) builds confidence faster.

Methods offered to fairly apportion the number of flights for countries of varying size have been based on relative size of the countries' entire territory, their searchable territory, their military, and their population.

Territorial Restrictions

In the broadest of all aerial surveillance schemes, aircraft would be free to roam where they please. In the interest of flight safety, however, some restrictions might be deemed necessary. Active military exercise or test sites might have to be bypassed unless there were a mandated stand-down period. Severe weather systems might also have to avoided, although these could be predicted by the inspecting country in advance. Moreover, adequate air traffic control might not be available in some areas.[74] Restrictions could also be adopted to ensure the safety of overflown facilities and people. The Soviets have made this argument in the Open Skies negotiations over such sites as nuclear power plants and major cities (see ch. 4).

The Soviets also believe it is necessary to restrict flights over sensitive facilities, where aerial surveillance might be used to gather information contrary to Soviet national security. By setting up exclusion zones, the Soviet Union would try to shield secret military and intelligence installations from prying Western eyes. To varying degrees, many other states agree with these concerns over the collection of collateral information, but they have tried to deal with them through means other than territorial restrictions. For example, the United States agreed that including SIGINT sensors in Open Skies would be too intrusive.

In some accords, free-ranging flight might not even be considered necessary. For example, overflights might be made only over designated regions (e.g., mobile missile deployment areas) or over declared facilities (e.g., chemical plants).[75] In the narrowest of schemes, tethered aerostats could be anchored at a specific site in order to observe local activities or site perimeters.

Details

If the central issues of a cooperative overflight regime were settled, there would still remain a host of details to work out. There are personnel questions such as who can be selected as an inspector or escort, whether a nominee can be rejected by the other parties, the inspectors' diplomatic status, and whether the inspector can be subjected to a physical search. There are questions of which party is responsible for what costs, including aircraft servicing and aircrew accommodations. A joint consultative mechanism also needs to be established to handle concerns over compliance and gray areas of the agreements.

Conclusion

Negotiators of aerial surveillance provisions must determine which types of platforms and sensors would be both effective in achieving the goals of the accord and still mutually acceptable. If the overflights were intended to be purely symbolic, then perhaps only visual observations by the aircrew would be required. In contrast, if overflights were a major component of a monitoring regime, a wide variety of complementary sensors, spanning the electromagnetic spectrum, might be essential. Negotiators making the final selection of the sensor and platform package would have to balance the strengths and weaknesses of the various airborne equipment with the costs and benefits of the agreement as a whole.

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[74] This may or may not be considered important. The United States itself has large areas that are not covered by air traffic control, but still permit flights.

[75] Restricting surveillance to designated sites undermines the ability of the flights to detect suspicious activities beyond these sites. In this sense, the flights begin to resemble some types of OSI: they can determine compliance at the designated site, and make cheating more difficult and expensive by shifting it elsewhere, but they cannot detect cheating off site.

Chapter 4

OPEN SKIES

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Chapter 4
OPEN SKIES

Summary

One example of how aerial surveillance might be used in a multilateral agreement can be found in the Open Skies Treaty intermittently being negotiated by the members of the North Atlantic Treaty Organization (NATO) and the now dissolved Warsaw Treaty Organization (WTO).[1]

The goals of the Open Skies Treaty are broad: to further international openness; to reduce tensions; to enhance military transparency and predictability; to further the progress of arms control; and to promote a more open Soviet society. In sum, the overall goal could be described as international confidence building. This is to be accomplished by opening the national airspace of the participants to relatively unrestricted overflights by aircraft carrying sensors and inspectors from other countries.

Designing a treaty to build confidence is a much more nebulous and subjective task than devising schemes for monitoring compliance with specific agreements. As of this writing, negotiations are stalled due to deep divisions between the United States and the Soviet Union over the degree of intrusiveness required to build an appropriate level of confidence. In general, the United States argues for maximal intrusiveness, while the Soviets hold out for tight restrictions on all aspects of the overflights. Other NATO and former WTO states tend to occupy the middle ground, but when pressed, lean toward the U.S. position.

Introduction

On May 12, 1989, during a speech at Texas A&M University, President George Bush resurrected President Dwight D. Eisenhower's 1955 proposal for a multilateral Open Skies Treaty. The Open Skies agreement he proposed would send NATO aircraft carrying sensors over Warsaw Pact countries and vice versa. The purpose was to use the characteristics of aerial surveillance to promote openness and to further reduce tensions in Europe. While the original proposal in 1955 was suffocated by an unfavorable political climate, the closing days of the Cold War offered more propitious conditions. (See table 4-1.)

Despite an initial period of public skepticism, the superpowers agreed to begin negotiations on the Open Skies initiative. Gradually, experts in the arms control field began to reconsider the utility of aerial surveillance as a component in international treaties. Just as the Intermediate-Range Nuclear Forces (INF) Treaty paved the way for broader discussions of the utility of on-site inspections, Open Skies seemed to move aerial surveillance into the realm of the practical.

Open Skies offers a detailed example of the issues involved in negotiating multilateral overflights. While most of these issues will surface in any negotiation on aerial surveillance, Open Skies does have one unique quality: its goals have been defined so broadly that no objective standard exists for establishing what the characteristics of the flights should be. Unlike a monitoring measure intended to search for a specific weapon system, inspect a site, or warn of a particular activity, Open Skies flights would aim to build confidence among the signatory countries.[2] As is discussed below, the vagueness of the goals of Open Skies has given Soviet negotiators some basis for their attempt to limit the intrusiveness of the treaty.

Open Skies—1955

In the summer of 1955, an Iron Curtain separated East and West Europe. Hard information about the intentions and military capabilities of the Eastern bloc was difficult to obtain. Early American attempts at clandestine aerial surveillance had been met by ever-increasing Soviet air defense capabilities. Overflights of Soviet territory by the super-

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[1] The military structures of the Warsaw Pact were abandoned Apr. 1, 1991. The final political remnants of the WTO were disbanded on July 1, 1911. (See "Warsaw Pact Formally Ends," *The Washington Post*, July 2, 1991, p. A11.

[2] As mentioned in ch. 2, the parties to the Open Skies negotiations agreed in principle that an Open Skies Treaty should support other arms control agreements. However, as the negotiations now stand, no such support has been written into the treaty. The Conventional Armed Forces in Europe (CFE) Treaty and the Strategic Arms Reductions Talks (START) are but two of the treaties and potential treaties that might benefit from overlapping monitoring coverage with Open Skies. However, such coverage would tend to be haphazard and incidental, since it is not being formally addressed in the negotiations.

Table 4-1—Open Skies Chronology

Date	Event
July 21, 1955	President Eisenhower's "Open Skies" speech; series of proposals follows.
April 29, 1958	Soviets veto final Eisenhower proposal for an Open Skies regime.
May 26, 1972	Strategic Arms Limitation Talks (SALT I) legitimize national technical means (NTM) of verification.
May 12, 1989	President Bush's Open Skies speech.
September 23, 1989	Soviet Foreign Minister Shevardnadze and U.S. Secretary of State Baker agree in principle to Open Skies concept and call for international conference on Open Skies.
September 25, 1989	Canada offers to host the Open Skies conference.
December 14-15, 1989	NATO ministers finalize a common Open Skies position.
January 4-7, 1990	Canadian-Hungarian mock overflight.
February 12-28, 1990	Open Skies first round, Ottawa, Canada.
February 13, 1990	Open Skies Communique.
April 24 to May 10, 1990	Open Skies second round, Budapest, Hungary.
May 12, 1990	One-year anniversary of President Bush's Open Skies speech; possible date for signing Open Skies Treaty passes without an agreement.
October 3, 1990	Unification of Germany.
April 1, 1991	Warsaw Treaty Organization's military organization is officially disbanded.
July 1, 1991	Warsaw Treaty Organization is formally dissolved.

SOURCES: *The Arms Control Reporter 1990; The Disarmament Bulletin,* Canada, External Affairs and International Trade, no. 12, winter 1989/90; "Warsaw Pact Formally Ends," *The Washington Post,* July 2, 1991, p. A11; and the Office of Technology Assessment, 1991.

secret, high-altitude U-2 aircraft and GENETRIX reconnaissance balloons[3] were still a year away; and only in March of 1955 had the U.S. Air Force issued a formal system requirement for a reconnaissance satellite.[4] This situation fostered Western concerns about the potential for a surprise attack by the Soviet Armed Forces, newly equipped with nuclear weapons.

In an effort to lift the curtain, President Eisenhower proposed, at the Geneva Conference of Heads of Governments (United States, United Kingdom, Soviet Union, and France) on July 21, 1955, the establishment of a system of mutual overflights by unarmed reconnaissance aircraft. In this well-known "Open Skies" speech, Eisenhower evoked the specter of nuclear war in his call for a system of mutual aerial surveillance:

> I should address myself for a moment principally to the delegates of the Soviet Union, because our two great countries admittedly possess new and terrible weapons in quantities which do give rise in other parts of the world, or reciprocally, to the fears and dangers of surprise attack.[5]

But Eisenhower saw Open Skies as more than simply a warning mechanism. He also believed that Open Skies would lead to a lessening of tension and general danger, and eventually to "a comprehensive and effective system of inspection and disarmament."[6]

The specifics of Eisenhower's proposal included an exchange of "a complete blueprint of . . . [each side's] . . . military establishment,"[7] identical facilities for aerial photography, and allowance for the removal of photographs for study. The French and British Governments quickly agreed to join in this system.

At the time of its announcement, Open Skies was a revolutionary concept that offered to enhance radically the quantity and quality of information available to each superpower about the other. However, the Soviet Government still equated its security with absolute secrecy, and therefore eventually rejected the U.S. proposal as an effort to spy on the Soviet Union.

Over the next 2 years, the United States, through the United Nations and bilaterally, sought to find some way to make Open Skies work. These efforts focused on limiting the regime geographically to the Arctic countries, including the United States, the Soviet Union, Canada, and the Nordic states. The

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[3] See box 6-I in ch. 6.

[4] Merton E. Davies and William R. Harris, *RAND's Role in the Evolution of Balloon and Satellite Observation Systems and Related U.S. Space Technology* (Santa Monica, CA: The RAND Corp., 1988), p. 61.

[5] Dwight D. Eisenhower, "Statement on Disarmament Presented at the Geneva Conference," July 21, 1955 as cited in Dwight D. Eisenhower, *Public Papers of the Presidents of the United States 1955,* No. 166, p. 715.

[6] Ibid., pp. 715-716.

[7] Ibid., pp. 715.

Photo credit: U.S. Air Force

Lockheed U-2R aircraft in flight.

Soviet representative at the United Nations Security Council vetoed the final American attempt to find some basis for an Open Skies agreement on April 29, 1958.[8]

Open Skies—1989

The original Open Skies proposal lay dormant for nearly three and a half decades. Then, President Bush judged that the international political climate had changed sufficiently for another attempt at negotiating a mutual overflight agreement. This time, the Soviet Union appeared to decide that its security would not be severely undermined by an Open Skies regime and might in fact be strengthened. Part of the reason for this changed attitude was undoubtedly the fact that the superpowers had essentially already had their skies opened with the orbiting of sophisticated reconnaissance satellites beginning in the 1960s.[9]

Moreover, in 1989 the world community was receptive to a resumption of Open Skies talks. In particular, the acceleration of reforms in the Soviet Union and Eastern Europe and the completion of an agreement on intermediate-range nuclear missiles in Europe, which included a verification regime of unprecedented intrusiveness, invoked both the optimism and cooperative spirit necessary for a pan-European agreement. Simultaneously, fears of instability and of the threat from residual military capabilities made monitoring important to a growing list of nations. Without the changed political climate, Open Skies would remain nonnegotiable; without the fears, Open Skies would not be necessary.

On May 12, 1989, in an address to graduating students at Texas A&M University, President Bush revived President Eisenhower's proposal for an Open Skies agreement:

> Thirty-four years ago, President Eisenhower met in Geneva with Soviet leaders who, after the death of Stalin, promised a new approach toward the West. He proposed a plan called Open Skies, which would allow unarmed aircraft from the United States and the Soviet Union to fly over the territory of the other

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[8] *The Arms Control Reporter: A Chronicle of Treaties, Negotiations, Proposals, Weapons, and Policy* (Brookline, MA: Institute for Defense and Disarmament Studies, 1990), p. 409.B.1.

[9] These overflights were legitimized with the ratification of the Strategic Arms Limitations Talks agreements in 1972 which recognized the use of national technical means (NTM) of verification. The Soviet Union accepted the principle that national sovereignty does not extend into outer space in a 1963 United Nations resolution. (See Michael B. Beschloss, *Mayday: Eisenhower, Khrushchev, and the U-2 Affair* (New York, NY: Harper & Row, 1986), p. 393).

Box 4-A—Canadian-Hungarian Trial Overflight[1]

Outside the United States, perhaps the strongest advocate for an Open Skies regime has been the Canadian Government. This interest goes back to the inception of the idea in 1955 when Canada became the first Western nation to endorse formally President Eisenhower's proposal.[2] In September 1957, Prime Minister John Diefenbaker made this statement:

> . . . the Canadian Government has agreed, if the Soviet Union will reciprocate, to the inclusion of either the whole or a part of Canada in an equitable system of aerial inspection and will do its utmost to ensure that the system works effectively.[3]

This interest has carried over to the present. Prime Minister Brian Mulroney made his support of Open Skies clear to President Bush even before the public address.[4] And as mentioned above, the Canadian Government quickly offered to host the first round of the talks.

In an effort to get the conference off on the right foot, the Canadian Government proposed, and the Hungarian Government accepted, a mock aerial surveillance flight over each of their countries. The purpose of the flights was to demonstrate that the procedures involved in Open Skies would be safe, nondisruptive, and practical. The two countries opted not to allow sensors on the test plane and instead concentrated on facilitating the preflight inspection for contraband and on gauging the success of air traffic control of an airplane with an unconventional flight plan (outside commercial air corridors).

Crossing Czechoslovakia, a Canadian Forces C-130 airplane arrived in Budapest, Hungary on January 4, 1990 for the first of the two flights. The time intervals for each aspect of the flight from arrival to departure were expanded somewhat to allow a detailed analysis and discussion of the proposed procedures. Hungarian authorities, watched by the Canadian aircrew, inspected the plane for armaments for about 4 ½ hours (normally, this inspection would also look for illegal sensors and, perhaps, verify the specifications of the legal sensor suite). At the same time, the Canadian crew submitted its intended flight plan to the Hungarians, who had 24 hours to clear the route and ensure its safety.

On the morning of January 6, 1990, the C-130, along with its Canadian crew and Hungarian observers,[5] flew a figure-8 route over Hungarian territory for about 3 hours. The plane changed altitude several times during the flight from approximately 5,000 to 16,000 feet.[6] The flight plan took the plane over a variety of commercial and residential areas as well as Hungarian and Soviet military installations.

Declared a general success by the participants, the trial flight was said to demonstrate that Hungarian air traffic control could handle the unusual flight path without undue effort or expense. One concern raised was that host-country escorts during the preflight inspection might inadvertently damage the plane and undermine flight safety. The participants felt that providing manuals for the plane and appropriate tools for opening flight instruments could be a partial solution to this safety problem. On January 7, 1990, the Canadian plane left Budapest.

Neither Hungary nor any other WTO member has taken advantage of Canada's offer of a reciprocal overflight of Canadian territory.

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[1] Details of the aerial surveillance exercise can be found in the following sources: Canada, External Affairs and International Trade, "Report on the Canada-Hungary Trial 'Open Skies' Overflight, Jan. 4-6, 1990, *Open Skies: Preparing for the 1990s*, Backgrounder No. 3, Feb. 1, 1990; "Canada Conducts Trial Open Skies Overflight of Hungary," *The Disarmament Bulletin*, Canada, External Affairs and International Trade, No. 12, winter 1989/90, pp. 7-8; "Open Skies Treaty Will Give 23 Nations Surveillance Rights," *Aviation Week and Space Technology*, Feb. 19, 1990, p. 21; *The Arms Control Reporter 1990*, p. 409.B.6-8; and "Canadian Flight Over Hungary Marks Trial Run of U.S. Open Skies Initiative," *Defense News*, Jan. 15, 1990, p. 25.

[2] Michael Slack and Heather Chestnutt (eds.), *Open Skies: Technical, Organizational, Operational, Legal, and Political Aspects* (Toronto, Canada: Center for International and Strategic Studies, York University, February 1990), p. 105.

[3] "What Canada Said," *The Disarmament Bulletin*, Canada, External Affairs and International Trade, No. 12, winter 1989/90, p. 4.

[4] Ibid., p. 4.

[5] The escorts were free to move about the plane as they saw fit. However, since there were no sensors aboard the plane, there was little for them to observe besides that the plane did not stray from its planned course.

[6] It was concluded that for reasons of safety the minimum altitude for any overflight should be 2,000 feet above the highest obstacle within 10 nautical miles of the flight path.

> country. This would open up military activities to regular scrutiny and, as President Eisenhower put it, "convince the world that we are lessening danger and relaxing tension."
>
> President Eisenhower's suggestion tested the Soviet readiness to open their society. And the Kremlin failed that test.
>
> Now, let us again explore that proposal, but on a broader, more intrusive and radical basis, one which I hope would include allies on both sides. We suggest that those countries that wish to examine this proposal meet soon to work out the necessary operational details, separately from other arms control negotiations.
>
> Such surveillance flights, complementing satellites, would provide regular scrutiny for both sides. Such unprecedented territorial access would show the world the true meaning of the concept of openness. The very Soviet willingness to embrace such a concept would reveal their commitment to change.[10]

As a side effect, the proposal generated renewed interest in using aerial surveillance for a wide variety of other monitoring and confidence-building tasks. (Some of these are discussed in the next chapter.)

On September 22-23, 1989, Soviet Foreign Minister Eduard Shevardnadze and U.S. Secretary of State James A. Baker III met in Jackson Hole, Wyoming, where they released a joint statement agreeing in principle to the Open Skies concept and calling for an international conference. Two days later, the Canadian Government offered to host the conference in its capital.[11]

Then, in mid-December in Brussels, the 16 NATO foreign ministers gathered at NATO headquarters and hammered out the final details of a joint NATO position that covered virtually all aspects of a potential accord. They sought to keep the agreement flexible, simple, and, above all else, minimally constrained.[12]

In January 1990, the Canadian and Hungarian Governments set the stage for the Ottawa Conference by conducting a mock Open Skies overflight of Hungarian territory (see box 4-A). When the first round of talks began, a wide gap appeared between NATO's opening position and that of the Warsaw Pact. The resulting draft treaty did little to narrow the significant differences.[13] The principal outcome of the Ottawa meeting was a joint communique on the second day. This statement laid the foundations both for future agreement and disagreement.

The second round (Apr. 24 to May 12, 1990) of Open Skies talks in Budapest, Hungary produced no further progress and quashed hopes for a signing ceremony on the 1-year anniversary of President Bush's Open Skies speech. Publicly, at least, the Open Skies negotiations have been stalled since the Hungarian Conference. As of this writing, no date has been set for a third round.

The Goals of Open Skies

According to the joint communique released at the Ottawa Conference, the 23 nations (22 nations after the unification of Germany) participating foresaw many benefits arising out of an Open Skies agreement:

> . . . although an "Open Skies" regime is neither an arms control nor a verification measure per se its successful implementation would *encourage reciprocal openness* on the part of participating states. It would *strengthen confidence* among them, *reduce the risk of conflict*, and *enhance the predictability of military activities* of the participating states. Finally it would *contribute to the process of arms reduction and limitation* along with verification measures under arms limitation and reduction agreements and existing observation capabilities. The Ministers noted further that the establishment of an "Open Skies" regime may *promote greater openness* in the future in other spheres.[14]

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[10] President George Bush, "Remarks at the Texas A&M University Commencement Ceremony in College Station, Texas," May 12, 1989 as cited in *Weekly Compilation of Presidential Documents*, vol. 25, No. 20, May 22, 1989, p. 702. (Paragraph breaks not in original text.)

[11] Ottawa Conference participants were the NATO countries (Belgium, Canada, Denmark, France, West Germany, Greece, Iceland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Turkey, the United Kingdom, and the United States) and the Warsaw Pact states (Bulgaria, Czechoslovakia, East Germany {until reunification}, Hungary, Poland, Romania, and the Union of Soviet Socialist Republics). Observers from Austria, Cyprus, Finland, Ireland, Monaco, Sweden, Switzerland, and Yugoslavia also attended.

[12] See app. D, U.S. Arms Control and Disarmament Agency, "NATO's Proposed Basic Elements for Open Skies," *Official Text*, Dec. 14-15, 1989.

[13] Jonathan B. Tucker, "Back to the Future: The Open Skies Talks," *Arms Control Today*, October 1990, p. 22.

[14] U.S. Arms Control and Disarmament Agency, " 'Open Skies' Communique," *Official Text*, Feb. 13, 1990.

From this passage and other statements by Open Skies participants, a general list of goals set for the treaty can be distilled:[15]

- enhance military transparency and predictability,
- reduce international tensions,
- further the progress of arms control, and
- promote a more open Soviet society.

As a whole, these broad goals can be described as confidence-building measures. The aerial surveillance provisions of the treaty are not intended to count treaty-limited items (TLIs), measure specific quantities, or monitor restricted behaviors; instead, they are primarily meant to provide assurance that the current political warming is continuing apace by making widely available information that demonstrates good intentions and nonthreatening capabilities. This vagueness has led to a debate (primarily between the Soviet Union and the other participants, but also among the other participants) as to the level of intrusiveness needed to accomplish the declared goals.

The Initial NATO Position

As mentioned above, the 16 NATO foreign ministers gathered December 14-15, 1989 at NATO Headquarters in Brussels to finalize a joint proposal for Open Skies. This proposal formed the basis for negotiations with the seven WTO member states. To limit the complexity of the talks and facilitate unanimous consent, the NATO ministers decided to restrict the Open Skies discussions to these two alliances.

Here, in brief, are the key operational details of the original NATO proposal. They are referenced by letter to ease comparisons between NATO and non-NATO positions in the following section. The bracketed citations correspond to the official text in appendix D.

A. Initially Open Skies negotiations will be between the NATO and WTO alliances {III}, but later they might include any other European nation {I.3}.

B. Open Skies flights will encompass the entire territory of the participants[16] and, in principle, will be limited only for reasons of safety or international law {I.4 and VIII.7}.[17]

C. An unarmed, fixed-wing military or civilian aircraft will be provided by the inspecting party. The plane will carry host-country observers during its overflight {V and VIII.6}.

D. Overflights may be conducted individually or jointly within alliances {I.4 and IV.1}.[18] Equipment and aircraft may be shared among allies {VII}.

E. The planes will be allowed to carry a wide variety of sensors. Only signals intelligence (SIGINT) devices will be banned {VI}.

F. All participants share a commitment to conduct and receive overflights on the basis of national quotas {I.4}. These quotas will set both the number and duration of overflights. The standard for the quota apportionment will be national geographical size {IV.1}. There should also be rough parity of quotas between NATO and the WTO and between the Soviet Union and the combined territories of the United States and Canada {IV.3}.[19] Larger countries should be subject to several overflights per month {IV.1}, and all nations must receive one flight per quarter {IV.4}. Smaller allied states may group themselves and act according to their combined geographical size {IV.5.}.

G. Overflights will begin and end at a Point of Entry (POE) and a Point of Exit, respectively {VIII.1}. These points can be the same {VIII.7}.

H. The host country will arrange service as for a commercial airliner {VIII.2}.

---

[15] As a proximate and unstated goal, Open Skies would add to the information-gathering capabilities of the participants, particularly the nonsuperpowers. These expanded capabilities, depending on their final negotiated parameters, could benefit the verification of other current and future treaties, provide a broad range of collateral intelligence, and add to strategic, and perhaps tactical, warning.

[16] For the United States this includes the 50 states, Guam, Puerto Rico, and the U.S. Virgin Islands.

[17] As spelled out by the United Nations-sponsored International Civil Aviation Organization (ICAO) and bilateral and multilateral accords.

[18] The Netherlands announced on Feb. 12, 1990, that it would conduct joint flights with Belgium and Luxembourg in order to reduce costs. Paul Lewis, *New York Times*, Feb. 13, 1990 as cited in *The Arms Control Reporter 1990*, op. cit., footnote 8, p. 409.B.9.

[19] At the Budapest Conference, the United States proposed to allocate quotas on a bilateral basis among all parties, superseding the original NATO proposal to allocate them by alliance. This was done in recognition of the gradual dissolution of the WTO. The new proposal raised the possibility that East European countries might be able, with Soviet permission, to overfly the Soviet Union. (Tucker, op. cit., footnote 13, pp. 22-23 and personal communication Apr. 5, 1991.)

Table 4-2—Asymmetric Advantages and Disadvantages in Open Skies

Region/state	Advantages	Disadvantages
Superpowers	Superpowers have more resources and better intelligence apparatuses; Open Skies data can cue NTM.	NTM already provides much of the information that Open Skies would provide, thus superpowers gain relatively less and lose relatively more than other nations.
Nonsuperpowers	Treaty puts superpowers and nonsuperpowers on equal political footing; gives these countries an independent means of surveillance.[a]	Fewer resources than superpowers.
NATO	Access to more closed societies.	No technology gain; technology loss to WTO.
Soviet Union	Might gain access to Western sensor and processing technology.	Least open society has the most information to be revealed.
Non-Soviet WTO	Might gain access to Western sensor and processing technology.	Least-capable sensor and processing equipment.

[a] France currently operates the commercial grade SPOT-Image photoreconnaissance satellite and is developing the *Helios* military reconnaissance satellite system with Spain and Italy.

SOURCE: Office of Technology Assessment, 1991.

I. The inspecting party must transmit an inspection notification 16 hours before arriving at the POE {VIII.3}. After arrival, the flight crew has an additional 6 hours to file a flight plan for the overflight {VIII.4}.[20] This done, the host country has 24 hours in which to inspect the plane for illegal devices and arrange for the flight {VIII.5}. (See figure 4-1.)

J. Loitering by aircraft over one spot is not permitted {VIII.6}.

K. Alliances will decide amongst themselves how to share overflight information {IX}.

The NATO position, as embodied in a U.S.-Canadian draft treaty, served as the basis for the joint working draft at the Ottawa Conference.

Points of Disagreement[21]

According to press reports, the Open Skies negotiations often did not follow the usual pattern of alliance versus alliance differences. Instead, individual nations—including for the first time the newly independent Eastern European countries—made proposals on their own initiative. The result has been a series of disagreements with and departures from the NATO baseline identified above.

In general, the United States has sought to maximize the openness of Open Skies arrangements as defined in the NATO Basic Elements. Although there have been signs of compromise, the United States continues to advocate relatively unrestricted overflight procedures and equipment. The other NATO allies, as well as the non-Soviet WTO member states, have been more flexible in the negotiations, but, "when push has come to shove," have tended to adopt the U.S. point of view. The Soviets, on the other hand, have so far blocked most efforts to reach a grand compromise (see table 4-2). In all areas, the Soviets consistently argue for the least intrusive regime, leading many observers to question whether the Soviet Union has really abandoned its historical demand for secrecy. That the goals of the treaty are so ambiguous and hard to translate into concrete terms (e.g., how many flights are needed to "reduce tensions?")[22] has left the Soviet negotiating team room to maneuver and stall.

The Soviets disagreed with points throughout the NATO proposal. It is ironic, though, that in most cases the Soviets cited as the basis for their dissent two agreed phrases from the joint statement of the Ottawa Conference:

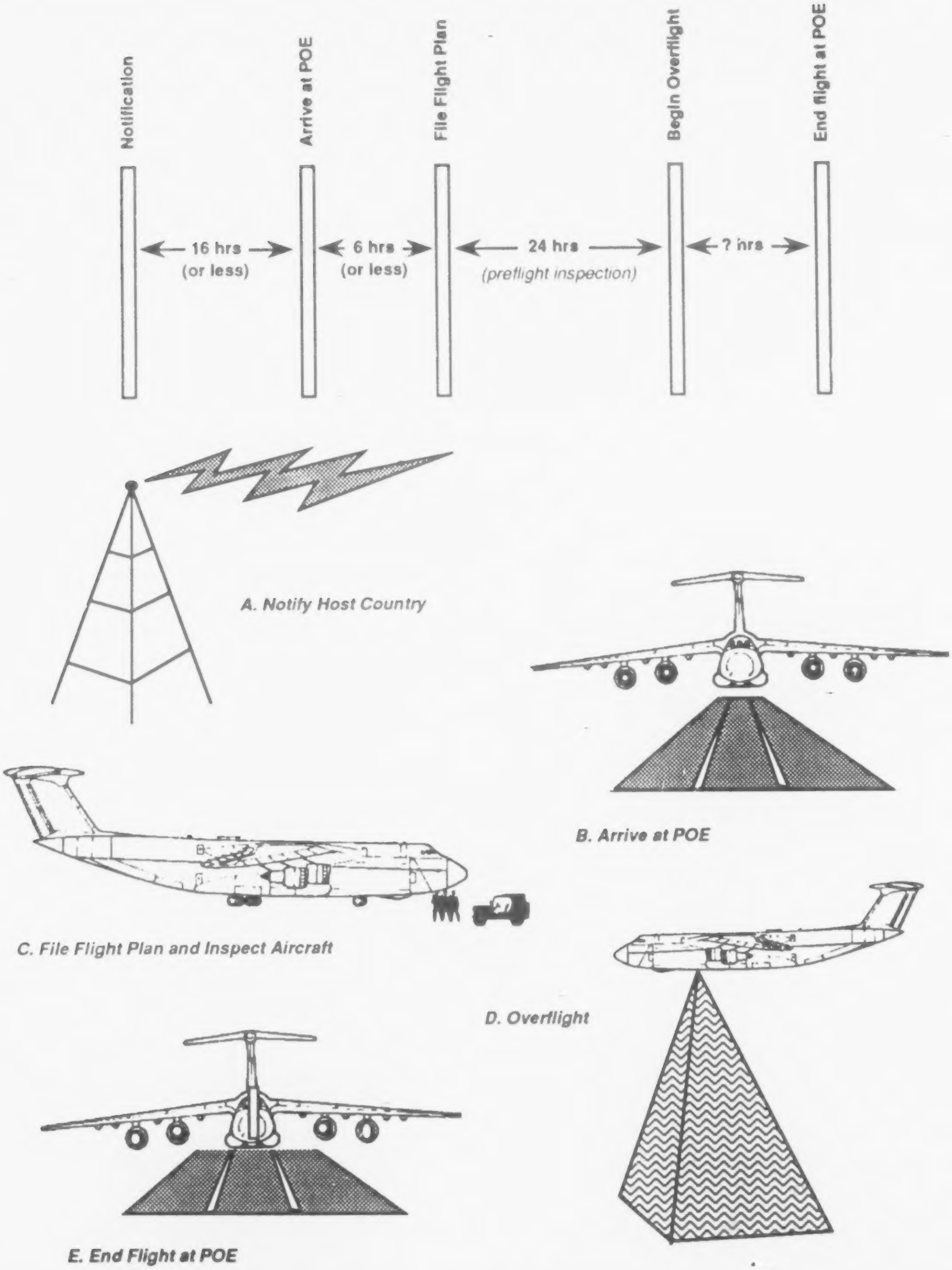
---

[20] The periods listed in this bullet for notification and flight plan filing are maximum values. The host country, in cooperation with the inspecting party, would retain the option to shorten these periods.

[21] This section (and indeed the entire report) is based on unclassified sources and therefore covers only those disagreements that have been expressed publicly.

[22] One analyst suggests that an unstated standard of adequacy for an Open Skies agreement is in fact emerging from the negotiating process: it is "to enable participants to identify rapidly massing military formations by the generic types of vehicles within them." Furthermore, participants should be able to accomplish this mission day or night, and in all weather conditions. This warning function for Open Skies gives negotiators a more definite target in their discussions. However, the Soviets have not formally recognized this standard for the agreement. See Peter Jones, "CFE Aerial Inspections and Open Skies: A Comparison" in Heather Chestnutt and Michael Slack (eds.), *Verifying Conventional Force Reductions in Europe: CFE I and Beyond* (Toronto, Ontario: Center for International and Strategic Studies, York University, 1991), p. 90.

Figure 4-1—NATO Proposed Timeline


Notification
Arrive at POE
File Flight Plan
Begin Overflight
End flight at POE
16 hrs (or less)
6 hrs (or less)
24 hrs (preflight inspection)
? hrs
A. Notify Host Country
B. Arrive at POE
C. File Flight Plan and Inspect Aircraft
D. Overflight
E. End Flight at POE

SOURCE: Office of Technology Assessment, 1991.

- "implemented on a reciprocal and equitable basis"; and
- "maximum possible openness and minimum restrictions."

The United States views the first point as a statement of equal opportunity and equal application of the rules. The Soviet Government argues that equality means a leveling of capabilities and minimizing burdens. On the second point, the United States maintains that openness should apply predominantly to territorial and sensor access, while the Soviets stress the sharing of equipment and collected information. These differing emphases are evident at each point of disagreement.

Participation in the conferences themselves has been one such point of contention. In item A of the above listing of NATO's position, the alliance insisted that the first phase of negotiations be open only to WTO and NATO members. The rationale was that fewer participants would make it easier to obtain a unanimous and relatively uncomplicated treaty. The Soviets, on the other hand, have questioned this rationale, with Soviet Deputy Foreign Minister Viktor Karpov declaring at one point, "Our opinion differs: All neutral and nonaligned CSCE [Conference on Security and Cooperation in Europe] countries should be included in this process if they so wish."[23] Thus, the Soviets argue for greater openness.

A second, and major, topic of dispute has been restrictions on the territory subject to overflights. As indicated in item B above, the NATO position calls for maximal coverage of national territory with restriction based solely on safety and international law. The Soviets, on the other hand, have sought to both restrict and expand the covered territories. First, they have argued for several types of exclusion zones:

> There are such zones in virtually all countries. And here neither military or civilian aircraft can fly—for example, over major cities or chemical or other ecologically dangerous enterprises, or nuclear power stations or water installations except in emergency situations. Why then should we make an exception to this rule for foreigners, thus subjecting the lives of our fellow citizens to extreme danger? Moreover, we still have regions that are closed in the interests of preserving state secrets.[24]

Not surprisingly, some of these restricted zones (particularly the ones preserving state secrets) are precisely the ones that NATO would like to see to advance the stated purposes of the treaty.

Then, the Soviets have argued on the grounds of equality and greater openness for the inclusion of member nations' military bases in other countries.[25] NATO has flatly rejected this proposal, because these countries would not be party to the treaty and their airspace is sovereign.

Soviet exceptions to items C, D, and H all revolve around the issue of whose planes will be used for overflights. The Soviet Government has sought to avoid being overflown by foreign aircraft. One reason for this was laid out by Soviet Deputy Foreign Minister Karpov:

> The present level of the development of electronics makes it possible to fit an aircraft with a tiny sensor which could collect a vast quantity of information having nothing to do with "Open Skies" and would be very difficult to detect by inspectors when checking someone else's aircraft.[26]

Moreover, the Soviets have argued that the cost of flying airplanes from the Soviet Union to North America would be prohibitive and unequal.[27] For these reasons, the Soviets have proposed alternatives to the NATO plan:

> We proposed the setting up of a single pool—we found no support. But our main idea is that there should be freedom of choice. If some state wishes its territory to be overflown by aircraft of its own design with standard equipment, a mixed crew, and a group of observers, this wish ought to be respected. If it wants an aircraft belonging to some third country—

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[23] S. Guk, "Does the USSR Advocate 'Open Skies' With Exclusion Zones? The Soviet Position Has Been Distorted. USSR Deputy Foreign Minister Viktor Karpov Replies," *Izvestiya*, Mar. 5, 1990, p. 3, as translated in Foreign Broadcast Information Service, *Soviet Union Daily Report*, FBIS-SOV-90-043, Mar. 5, 1990, p. 2.

[24] *Trud*, "The Spy Place 'Within the Law': An Interview With Major General V. Kuklev, First Deputy Chief of the General Staff," Mar. 27, 1990, p. 3, as translated in Foreign Broadcast Information Service, *Soviet Union Daily Report*, FBIS-SOV-90-063, Apr. 2, 1990, p. 3.

[25] See, e.g., *Trud*, ibid., p. 3; and Guk, op. cit., footnote 23, p. 3.

[26] V. Shelkov, "Interview for Pravda," *Pravda*, Mar. 4, 1990, as translated in Foreign Broadcast Information Service, *Soviet Union Daily Report*, FBIS-SOV-90-043, Mar. 5, 1990, p. 1.

[27] *Trud*, op. cit., footnote 24, p. 3.

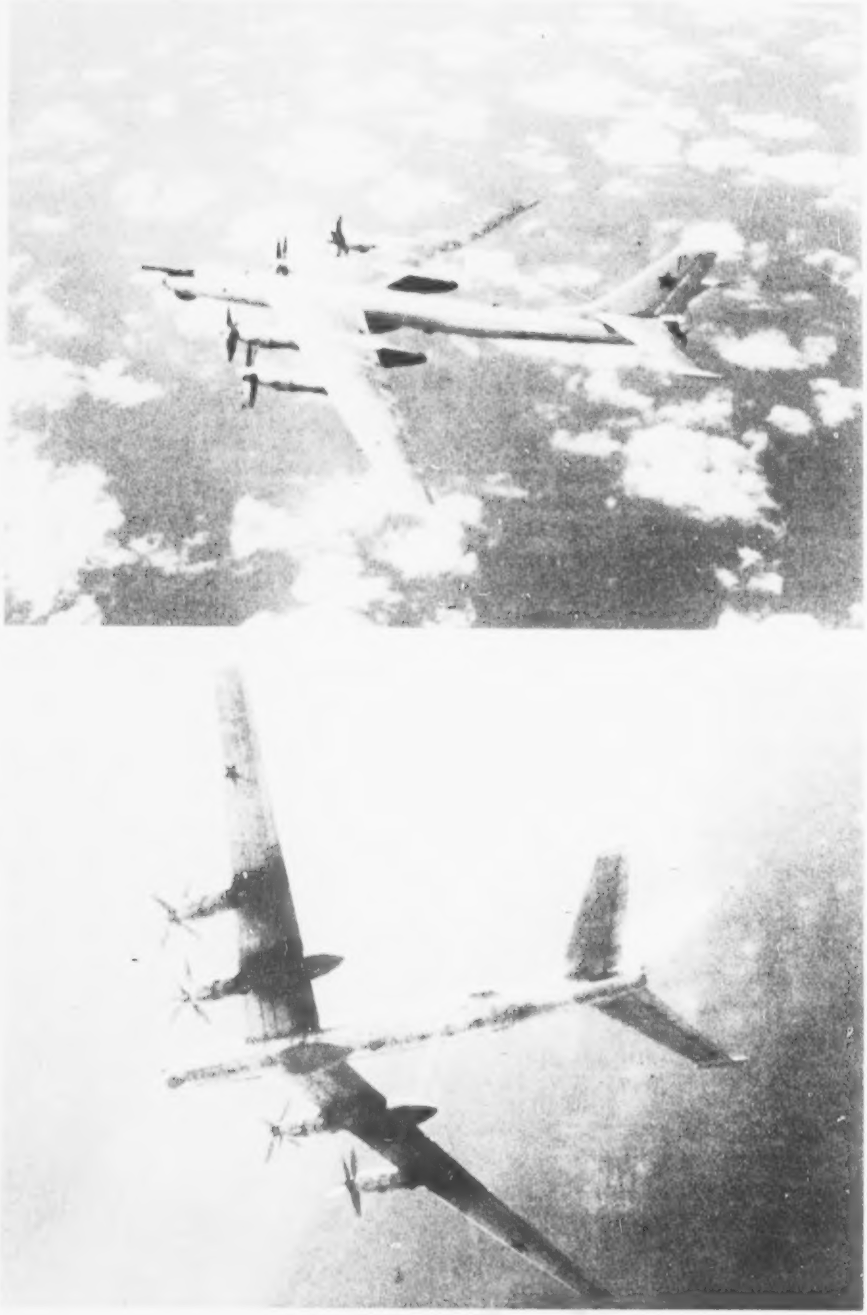

***Photo credit:** U.S. Air Force*

Source: Jane's All the World's Aircraft: 1990-91, Mark Lambert (ed.) (Coulsdon, Surrey, United Kingdom: Jane's Information Group, 1990), p. 281.

The Soviet Tu-95D Bear maritime reconnaissance aircraft, a variant of the Bear strategic bomber, is outfitted with radar domes (radomes) under its nose and midsection and electronic intelligence collectors on each side of its rear fuselage.

by all means. And finally, aircraft belonging to the monitoring side could overfly another state's territory only subject to its consent.[28]

Sensors (item E) have been a particular source of concern for the Soviets.[29] Up until the Budapest Conference, the Soviet Union wanted only standardized optical and electro-optical cameras; NATO advocated a wide variety of sensors with only a few listed restrictions (the primary one being a ban on SIGINT devices). NATO argues that the language of the Open Skies Communique on this issue is very clear: "The agreement will have provisions concerning the right to conduct observation flights using unarmed aircraft and equipment capable in all circumstances of fulfilling the goals of the regime."[30] The key phrase here is "equipment capable in all circumstances," which can reasonably be interpreted to encompass sensors that can function effectively day or night, rain or shine. Optical cameras that can see neither in the dark nor through clouds would clearly not suffice.[31]

At the Budapest round, the Soviets accepted the use of synthetic aperture radar (SAR) to achieve an all-weather capability. However, the SAR they proposed had a resolution of only 10 meters, compared to the 3-meter resolution thought necessary by most NATO states.[32] The Soviet compromise of 30 centimeters on optical resolution also exceeded the Western-proposed maximum of 15 centimeters.[33] The Soviets maintain that these resolutions are sufficient for the purposes of the treaty, and that any more information would begin to harm national security.

Some countries, particularly in Eastern Europe, are concerned about the inequality of sensor technology between the more advanced (typically Western) nations and the rest. On this basis they have called for standardized and simple hardware. This seems to be a natural request. On the other hand, these countries may be doing themselves a disservice. The NATO countries (through the United States) and the Soviets already have extensive intelligence capabilities outside of Open Skies. If advanced sensors were permitted in Open Skies, the less-capable nations would have the opportunity to develop and eventually deploy advanced and independent sensor systems. The United States has compromised on this issue, and is looking to ease trade restrictions in order to supply these countries with commercially available sensors.[34] Since sensors will most likely be subject to preflight inspection, the United States itself is inclined to adopt commercial technology for Open Skies to avoid compromising classified technologies.

On a related issue, the Soviets believe that sharing collected sensor data (item K) is the best way to fulfill the goals of the treaty:

> The "Open Skies" system must be imbued with the principle of universal and full equality. Equality in gaining access to information which cannot be used to the detriment of any of the parties.[35]

Information obtained during overflights would be shared at a new international agency:

> The data would be processed in a single center sited in any country. Parties to the agreement would pay for this also according to an agreed scale. The information arriving in this center should be available to all regardless, of course, of the financial contribution made by the different countries. This proposal of ours was rejected out of hand.[36]

The Soviets believe the NATO approach would be "detrimental":

> . . . the main content of the position expounded by U.S. representatives in Ottawa boils down to the fact that the United States, taking advantage of its technological potential, intends to overfly other

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[28] Guk, op. cit., footnote 23, p. 2.

[29] For a more complete discussion of sensors and sensor issues see ch. 3.

[30] " 'Open Skies' Communique," op. cit., footnote 14.

[31] Any country that had particularly overcast weather with low-level clouds would have an asymmetrical advantage if only optical cameras were used.

[32] *Arms Control Reporter 1990*, op. cit., footnote 8, p. 409.B.16

[33] Tucker, op. cit., footnote 13, p. 23-24.

[34] Jones, op. cit., footnote 22, p. 91.

[35] Eduard Shevardnadze, Soviet Foreign Minister, speech at Ottawa Conference, from Tass International Service, Feb. 12, 1990, as translated in Foreign Broadcast Information Service, *Soviet Union Daily Report*, FBIS-SOV-90-030, Feb. 13, 1990, p. 3.

[36] Shelkov, op. cit., footnote 26, p. 1.

> countries' territory, collect information, and tuck it safely away. So where is the "openness?"[37]

The NATO proposal would allow sharing information within alliances. The primary reason for not sharing information with nonallies is that it might help the observed country improve its camouflage, concealment, and deception techniques, because the inspected party could see precisely what the inspector could see. A second reason is that it could give some idea of just what objects the inspecting party was looking for. There has been some movement toward common ground by all the participants, except for the Soviets, who have yet to officially respond to the latest proposals. Raw data might be shared before it is processed.[38]

Finally, there have been disagreements on some of the specific numbers in the treaty. The Soviets have generally argued for fewer overflights (item F) than NATO. The Soviet Union has proposed 25 to 30 flights per year for each alliance,[39] of which 16 would be over the Soviet Union;[40] the United States has offered to receive about 52 flights per year with as many as 130 to 140 overflights per alliance.[41] (Complicating matters is the breakup of the Warsaw Pact and a possible shift to a matrix of bilateral quotas.) The Soviets also advocated at one point expanding the prearrival notification period (item I) up to 48 hours[42] and holding the time the sensors are activated to 3 hours.[43] It can be argued that these limitations would lessen the value of the overflights, and thus perhaps that of the treaty as well.

Conclusion

Soviet proposals and those of the other negotiating parties seem to reflect differing ideas about what is required to build confidence under Open Skies. The Western allies argue that Open Skies will be most effective in building confidence if restrictions on overflights and sensors are kept to a minimum. They believe that at a minimum the regime probably needs to provide some degree of warning of large-scale hostilities. The non-Soviet former WTO members are enjoying new freedom in the exercise of international diplomacy, but tend to agree with NATO on the details of an agreement.

The Soviets do not appear ready for the degree of openness sought by the West. In sum, negotiations remain stalled at this time.

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[37] Ibid., p. 1.

[38] Jones, op. cit., footnote 22, p. 98.

[39] Shelkov, op. cit., footnote 26, p. 1.

[40] *Arms Control Reporter 1990*, op. cit., footnote 8, p. 409.B.11.

[41] Shelkov, op. cit., footnote 26, p. 1.

[42] *Trud*, op. cit., footnote 24, p. 3.

[43] Shelkov, op. cit., footnote 26, p. 1.

Chapter 5

OTHER APPLICATIONS OF AERIAL SURVEILLANCE

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Chapter 5

OTHER APPLICATIONS OF AERIAL SURVEILLANCE

Summary

President George Bush's call in 1989 for a multilateral Open Skies Treaty resulted not only in Open Skies negotiations, but in a reexamination of the use of cooperative aerial surveillance for a wide variety of international applications. These applications include measures for confidence building (as in Open Skies) and monitoring (search, inspection, and warning).

Limited aerial surveillance in conjunction with on-site inspections (OSIs) is currently being used to observe large-scale military exercises in Europe under the Vienna Document of 1990. An extensive aerial surveillance regime is also being negotiated as a side agreement to the Conventional Armed Forces in Europe (CFE) Treaty that was signed on November 19, 1990. CFE overflights would be used as a complement to OSI and national technical means (NTM) of verification in monitoring treaty-limited items (TLIs).

Other possible applications for aerial observation can be found in a wide variety of potential international agreements. Agreements that limit objects or activities, that require measurements of chemical effluents in the air, or that provide for warning of threatening actions might utilize periodic overflights. Cooperative aerial surveillance, like NTM and OSI, is simply another form of observation. Whether to include aerial surveillance in a negotiated package depends on the characteristics of the items or activities being observed, the costs and benefits of the package, as well as its negotiability.

Introduction

Some Open Skies participants advocate expanding Open Skies to include not only the former members of the now dissolved Warsaw Treaty Organization (WTO) and the members of the North Atlantic Treaty Organization (NATO), but all European nations and perhaps others as well. At the same time, the CFE negotiators have committed their nations to further talks incorporating extensive aerial monitoring of compliance into the recently signed CFE Treaty. **This chapter discusses a variety of conceivable future negotiations that might include aerial surveillance, e.g., an extension of Open Skies, CFE, and a Chemical Weapons Convention. While exploring some of the possible applications of aerial surveillance, OTA neither advocates nor rejects them.**

Conference on Security and Cooperation in Europe and Open Skies

As mentioned in chapter 4, the Soviets (as well as some other participants) would like to invite those European nations not already included to join in the Open Skies negotiations. However, the NATO position is that an expansion of the talks at this time would only complicate the proceedings. Still, NATO stated in its initial proposal that it would be willing "to consider at an appropriate time the wish of any other European country to participate in the Open Skies regime."[1] As a first step, this could mean expanding participation to include not just the NATO and WTO states,[2] but the neutral and nonaligned (NNA) states as well.[3] These 34 nations already hold talks under the umbrella of the Conference on Security and Cooperation in Europe (CSCE).

The extension of Open Skies to all CSCE members would not be unprecedented. In 1986, the CSCE-sponsored Conference on Confidence- and Security-Building Measures and Disarmament (CDE)

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[1] See app. D, article I, section 3, paragraph 5.

[2] The NATO countries are Belgium, Canada, Denmark, France, West Germany, Greece, Iceland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Turkey, the United Kingdom, and the United States. The Warsaw Pact states were Bulgaria, Czechoslovakia, East Germany (until unification), Hungary, Poland, Romania, and the Union of Soviet Socialist Republics.

[3] There are four neutral countries (Austria, Finland, Sweden, and Switzerland) and eight nonaligned countries (Cyprus, the Holy See, Ireland, Liechtenstein, Malta, Monaco, San Marino, and Yugoslavia). The U.S. Government does not recognize the incorporation of the Baltic republics into the Soviet Union. Albania is the only other European nation not represented.

Photo credit: U.S. Army by Oswald Butler

U.S. Army officers listen to a Warsaw Pact observer of the 1987 NATO Reforger exercise in then-West Germany.

produced the so-called Stockholm Document[4] which permitted, among other things, aerial inspections[5] of large-scale military activities with no right of refusal (except in the case of *force majeure*), but only in host-owned and host-operated aircraft (including helicopters). No sensors were to be installed on the aircraft and inspectors were to carry only binoculars and hand-held cameras.[6] Strict quotas were set on inspections (both air and ground). Each state would be subject to at most three inspections per year. No single state could inspect another state more than once per year. The Stockholm Document was superseded by the Vienna Document of 1990, which reaffirmed its predecessor and added further confidence- and security-building measures. As of June 15, 1990, 40 inspections had been conducted.[7]

Either the Vienna Negotiations on Confidence- and Security-Building Measures (CSBM) or a revived CDE may be the most appropriate established forum for Open Skies under the CSCE framework. (The CDE was split into the CSBM and the CFE talks—both opening on March 9, 1989.)[8] The CSCE, however, except in the case of CFE, has traditionally limited its territorial jurisdiction to the European continent, thus excluding North America. Alternately, the Open Skies talks could simply take more petitioners under their umbrella. Eventually, the concept of Open Skies could be broadened by inviting individual states into the system on a case-by-case basis, by taking all comers, or by moving the talks to the United Nations.

Conventional Armed Forces in Europe

The CFE nations are negotiating, somewhat in parallel with Open Skies, an aerial inspection protocol that was intended to be part of the monitoring arrangements for the Conventional Armed Forces in Europe Treaty. The 7 (now 6) WTO states and the 16 NATO nations—the same group as in Open Skies—opened CFE negotiations in March 9, 1989 with the goal of equalizing and reducing conventional force levels in the Atlantic Ocean to the Ural Mountains (ATTU) region. They signed a treaty during the CSCE Paris Summit of November 19-21, 1990. This treaty included provisions for brief host-operated helicopter flights over inspection sites,[9] but set aside more extensive and intrusive aerial monitoring provisions to be negotiated with other loose ends in discussions dubbed ''CFE IA.''[10] Apparently, the parties believed that the CFE verification regime consisting of NTM, limited helicopter flights, and other cooperative measures including OSIs was sufficient for ratification. This implies that the aerial monitoring provisions of CFdE IA will be supplementary, and not essential.

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[4] The Stockholm Document entered into force on Jan. 1, 1987. Its official title is the Document of the Stockholm Conference on Confidence- and Security-Building Measures and Disarmament in Europe Convened in Accordance With the Relevant Provisions of the Concluding Document of the Madrid Meeting of the Conference on Security and Cooperation in Europe. For full text, see app. 10A in Stockholm International Peace Research Institute, *Sipri Yearbook 1989: World Armaments and Disarmament* (New York, NY: Oxford University Press, 1987).

[5] Ibid., paragraph 76 of the Stockholm Document.

[6] Ibid., paragraph 87 of the Stockholm Document.

[7] See U.S. Arms Control and Disarmament Agency, "Strengthening Stability Through Openness: The Vienna Negotiations on Confidence- and Security-Building Measures," July 1990, pp. 16-19.

[8] There is some overlap between CSBM and CFE, but in general CSBM deals with pan-European confidence- and security-building measures (including inspections and observations) and CFE focuses on NATO-WTO conventional force reductions.

[9] These overflights are described in the CFE Protocol on Inspection, section VI, paragraphs 16-21. Although the parties involved in an overflight can agree to other terms, the standard provisions permit the inspecting country to specify in advance whether an inspection is to be conducted by foot, cross-country vehicle, helicopter, or a combination of all three. If the area to be inspected is less than 20 square kilometers and an overflight is requested, the host country must provide a helicopter large enough to carry two inspectors and one escort and fly them over the site for not more than 1 hour total. The pilot must allow the inspectors "a constant and unobstructed view of the ground" during which time the inspectors can use any of their equipment (portable passive night vision devices, binoculars, video and still cameras, dictaphones, etc.). The host country may delay, limit, or refuse flights over sensitive points, but must permit the rest of the site to be overflown.

Although CFE and Open Skies overflights are being negotiated by the same set of states (NATO and former WTO) and may end up with very similar operational procedures and technologies, crucial differences exist between the two aerial surveillance regimes.

The most significant difference is that, unlike Open Skies, CFE surveillance flights will help monitor compliance with specific treaty provisions, in addition to building confidence in general. Monitoring tasks might involve counting legal TLIs,[11] searching for and documenting illegal TLIs, observing exercises and troop movements, inspecting closed-out facilities and eliminated TLIs, and pre-OSI surveys. According to a Canadian diplomat, the Soviets have tried to limit the scope of the protocol solely to observing compliance; i.e., confirming that legal TLIs are located at permitted sites. The other CFE participants argue that the overflights must be able to search for violations of the treaty beyond declared sites, and in this way, also act as a deterrent to such violations.[12] CFE flights, like Open Skies flights, could, of course, also build confidence, but as the result of confirmed treaty compliance.

The primary CFE TLIs are battle tanks, armored combat vehicles (ACVs),[13] artillery, combat aircraft, and attack helicopters. To monitor such small TLIs will most likely require more advanced sensor capabilities (most notably, higher imaging resolution) than a minimal Open Skies regime.[14] As discussed in chapter 3, it takes one grade of resolution to detect an object (e.g., ''There's something there.''), another to recognize the object (e.g., ''It's a tank.''), and quite another to identify it from technical details (e.g., ''That tank is a Polish T-72.'').[15]

Photo credit: Department of Defense

One CFE TLI is the battle tank. Defined by weight and weapon capability, battle tanks will be limited to 20,000 per alliance within the treaty's area of application.

A second major difference between Open Skies and CFE overflights is their respective territorial coverage: while CFE encompasses only the ATTU region of Europe, Open Skies includes all the territory of the participants. Most importantly, it also includes Soviet territory east of the Ural mountains. (Soviet military equipment reportedly has been transferred beyond these mountains to avoid being destroyed under the recently signed CFE Treaty.[16])

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[10] Article XIV, paragraph 6 and article XVIII. (CFE IA has also been referred to as CFE 1A in the West and Vienna-1A by the Soviet official news agency TASS. See for example, ''Karpov Meets NATO Official for CFE Talks,'' Moscow TASS in English, Dec. 3, 1990, in Foreign Broadcast Information Service, *Soviet Union Daily Report*, FBIS-SOV-90-233, Dec. 4, 1990, p. 1.)

[11] Also referred to as ''treaty-limited equipment'' or TLE, this second term neglects the possibility that facilities and structures might also be limited.

[12] *The Arms Control Reporter: A Chronicle of Treaties, Negotiations, Proposals, Weapons, and Policy* (Brookline, MA: Institute for Defense and Disarmament Studies, 1990), p. 409.B.18.

[13] The term ACV includes armored personnel carriers (APCs), armored infantry fighting vehicles (AIFVs), and heavy armament combat vehicles (HACVs).

[14] As was stated in ch. 4, Peter Jones believes that an all-weather, round-the-clock warning of massing forces has become the underlying standard of adequacy in the Open Skies talks. [See Peter Jones, ''CFE Aerial Inspections and Open Skies: A Comparison'' in Heather Chestnutt and Michael Slack (eds.), *Verifying Conventional Force Reductions in Europe: CFE I and Beyond* (Toronto, Ontario: Center for International and Strategic Studies, York University, 1991), p. 90.] The Soviets have not formally accepted this mission for Open Skies and argue more for symbolic flights. In either case, the requirement of CFE sensors to distinguish among types of TLIs and to count numbers accurately suggests a more extensive and sophisticated regime than that of Open Skies.

[15] See table 3-2 for targets and necessary ground resolution.

[16] ''Figures Row Suspends CFE,'' *Jane's Defence Weekly*, Mar. 2, 1991, p. 290.

Box 5-A—Airborne Monitoring of Chemical Weapons—Three Cases

The size of the chemical stockpiles to be monitored and their supporting infrastructure are important considerations when evaluating the potential success of aerial monitoring in supporting the goals of an agreement.

A group could both make and store sufficient amounts of chemical agent for its terrorist acts (measured in gallons) in just about any building. Overhead imaging sensors would reveal no clues to this activity and door-to-door searches would be impractical and prohibitively expensive (as well as illegal in many countries). Extremely sophisticated air sniffers and samplers might narrow the area of search, but probably not appreciably so. Thus, the role for aerial surveillance appears dubious.

However, in the case of chemical stockpiles sufficient for waging war between nations (measured in hundreds or thousands of tons), the potential role for aerial monitoring grows. Such a capability entails not only substantial chemical weapon production and storage facilities, but also the development of reliable delivery systems and, to some extent, operational training. Clearly, the number of potentially observable secondary characteristics grows with the size of the chemical stockpile and its support infrastructure.

If the negotiators of a potential chemical arms accord are concerned only with revealing militarily significant quantities of chemical weapons in time for other signatories to take appropriate counteractions, then aerial surveillance might be useful. Overflights in this case would no longer be looking for laboratories hidden in basements, but for large-scale chemical plants and storage areas, test ranges, and chemical offensive exercises. Thus, unlike the terrorist case, an aerial monitoring system, in conjunction with national technical means (NTM) of verification and on-site inspection (OSI), might be useful.

The enormous chemical stockpiles of the Soviet Union and the United States (measured in tens of thousands of tons) were designed to be used in a massive Central European conflict between two well-protected alliances.[1] They were meant at least as much to slow down and impair military activities on a continental scale as to inflict casualties. Although any nation possessing chemical weapons might use them in war, such huge quantities are held only by the world's two military superpowers. The United States and the Soviet Union have other means of mass destruction, as well as awesomely powerful conventional capabilities, that can compensate for large (interstate-size) covert chemical stockpiles secreted by the other. They also both have extensive intelligence assets that can warn them of threatening activities. Therefore, the requirements placed on an aerial monitoring regime might not need to be as stringent as for the other cases.

[1] The purpose of the United States stockpile is to deter Soviet first use.

Furthermore, overflights would commit the North American participants—the United States and Canada—to receiving overflights, something CFE would not do. That the United States and Canada would share some of the overflight burdens could make Open Skies a politically desirable adjunct to CFE aerial monitoring.[17] (Figure 5-1 illustrates the overlapping territorial coverage of overflights of three negotiating fora in Europe.)

The few publicly revealed disagreements over the CFE aerial monitoring protocol resonate with those of Open Skies. For example, NATO again advocates using its own aircraft for its inspections; the former WTO nations insist that the host country's aircraft be used.[18] But because the procedures needed to achieve the goals of CFE overflights can be defined more concretely than those of Open Skies, perhaps these disagreements can be more easily resolved.

Aerial monitoring provisions beyond those now being discussed in CFE IA could also be negotiated in the CFE follow-on talks proposed by NATO on August 30, 1990. The so-called CFE II talks would provide an opportunity to fine-tune the original CFE

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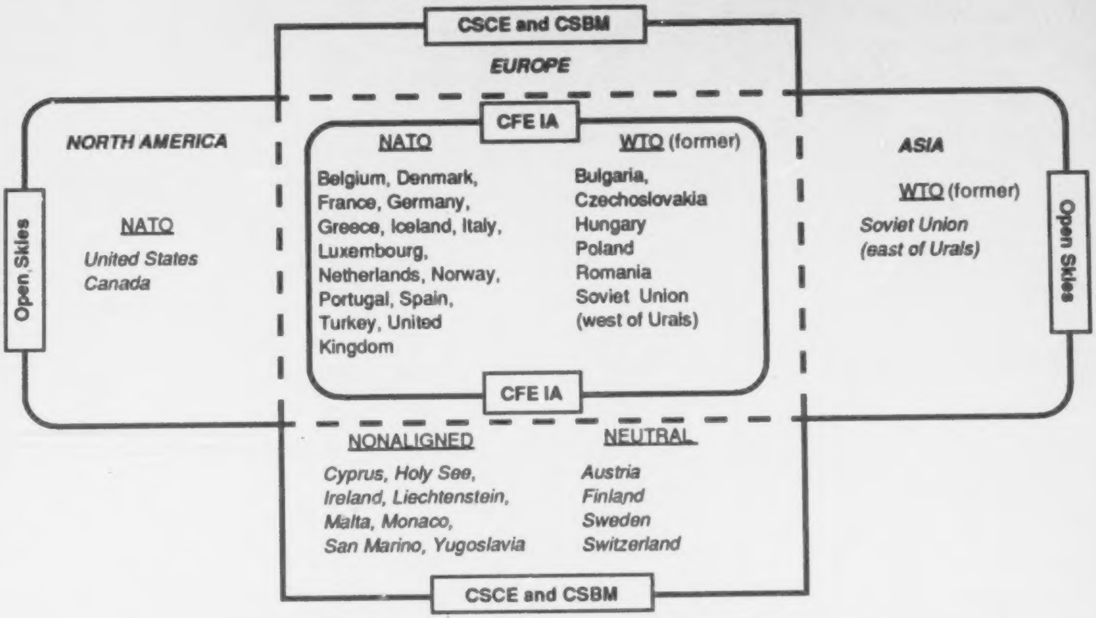
[17] Joe Clark, Canadian Secretary of State for External Affairs, ''Foreword: Open Skies,'' in Michael Slack and Heather Chestnutt (eds.), *Open Skies: Technical, Organizational, Legal, and Political Aspects* (Toronto, Canada: Centre for International and Strategic Studies, York University, February 1990), pp. *vi-vii.*

[18] Timothy J. Pounds, ''Context for Technologies That Monitor CFE Compliance,'' *Verification Technologies Review*, vol. 2, No. 4, July/August 1990, p. 7.

Figure 5-1—Territory Subject to Overflights in Various Talks


CSCE and CSBM
EUROPE
NORTH AMERICA
Open Skies
NATO
United States
Canada
CFE IA
NATO
Belgium, Denmark, France, Germany, Greece, Iceland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Turkey, United Kingdom
WTO (former)
Bulgaria, Czechoslovakia
Hungary
Poland
Romania
Soviet Union (west of Urals)
CFE IA
ASIA
WTO (former)
Soviet Union (east of Urals)
Open Skies
NONALIGNED
Cyprus, Holy See, Ireland, Liechtenstein, Malta, Monaco, San Marino, Yugoslavia
NEUTRAL
Austria
Finland
Sweden
Switzerland
CSCE and CSBM

The United States Government does not recognize the incorporation of the Baltic republics into the Soviet Union. Albania is the only other European nation not represented.

SOURCE: Office of Technology Assessment, 1991.

IA overflight procedures, as well as add new capabilities to advance the goals of the CFE process.[19]

Chemical Weapons Convention

The talks on reducing and banning chemical weapons currently under way both at the multilateral Conference on Disarmament (CD) and bilaterally between the United States and the Soviet Union offer other opportunities for the introduction of aerial monitoring (although provisions for overflights are not now being negotiated). There has also been some international discussion of creating chemical-weapon-free zones in Central Europe, the Balkans, and Southeast Asia.

Since 1980, the 40 member states of the Chemical Weapons Ad Hoc Committee at the CD, under the auspices of the United Nations, have been working to draft a ban on chemical weapons.[20] These discussions have led to several inspection demonstrations using chemical sampling and sniffing technologies, but none of these demonstrations has involved an airborne platform.[21] Similarly, the U.S.-USSR negotiations on chemical weapons, which began on June 28, 1984, are incorporating intrusive monitoring techniques.[22]

A notional agreement restricting chemical weapons could, among other things, authorize cooperative overflights to:

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[19] Because of rapidly changing events in Eastern Europe, the alliance basis for the CFE talks will probably not survive until a second CFE agreement can be signed. If this is the case, CFE might become a discussion between NATO and the individual nations of the WTO, or it could be moved to another forum altogether.

[20] *Arms Control Reporter 1990*, op. cit., footnote 12, p. 704.A.1.

[21] The U.S. chemical industry is already subject to aerial inspection by Environmental Protection Agency aircraft. (Amy Smithson and Michael Krepon, "Strengthening the Chemical Weapons Convention Through Aerial Monitoring," Occasional Paper #4, The Henry L. Stimson Center, Washington, DC, April 1991, p. 8.)

[22] *Arms Control Reporter 1990*, op. cit., footnote 12, p. 704.A.4.

- directly monitor compliance with the agreement (as in CFE);
- observe and warn of prohibited activities, e.g., illegal build-ups of weapons, redeployment of weapons, or training exercises (as in CDE);
- collect information (such as optical and infrared photographs) on sites that could help prioritize and focus OSIs;[23]
- document destroyed production plants;[24] or
- build confidence and trust (as in Open Skies).

The following example of one possible use of aerial surveillance in support of a chemical weapons agreement will focus on the first of these roles. These overflights might be conducted by individual states or collectively as a group with common aircraft and sensors.

If the goal of a chemical weapon overflight agreement is monitoring compliance, the characteristics of the TLI are a key issue. Unlike the battle tanks and combat aircraft of CFE, however, chemical agents (liquids and gases) and chemical munitions (relatively small shells and bombs containing chemical agents) do not readily lend themselves to direct observation from the usual airborne imaging sensors.

If the monitoring regime allowed chemical samplers or sniffers, it might be possible to collect a minute sample of a chemical agent, although the release of agents into the atmosphere would be tightly controlled for obvious reasons. Even if a violation were detected, supporting indirect evidence from other sensors or a follow-up inspection on the ground might be desirable, if for no other reason than to verify that the airborne chemical agent did not float in from some other country or was not planted by the inspecting team.

The difficulty of uncovering direct evidence of a violation means that the presence of covert production, storage, and, conceivably, deployment areas may have to be inferred from the discovery of secondary characteristics of chemical agents and munitions. These characteristics or indicators might include unusual safety or security measures; industrial structures similar to chemical or pesticide plants; chemical storage tanks; proximity to shell casing or missile manufacturing plants or storage sites; or the presence of precursor chemicals or byproducts in the air.

Precursors are chemicals that are combined to create a toxic agent; byproducts are chemicals that remain after the agent is complete. Some of these chemicals are used in a variety of products that have nothing to do with chemical warfare. Because some may be relatively harmless, controls on their escape into the atmosphere might be less secure. The presence of one or a few comparatively rare precursors or byproducts could be added to the list of secondary characteristics of weapon production.[25]

In cases where only indirect evidence of a violation is exposed, some other mechanism must be established for determining noncompliance. This mechanism might take the form of a human suspect-site or invitational inspection.[26] Thus, a potential role for overhead imaging sensors and sniffers in a chemical weapon accord would be to detect possible covert production or storage of chemical weapons by examining secondary characteristics, and then to pass the information along to an inspection team that would investigate the site more closely.

Other Potential Applications

Several other potential arms control agreements might conceivably benefit from aerial surveillance: a Short-Range Nuclear Forces (SNF) accord, a Strategic Arms Reduction Talks follow-on agreement (START II), or regional conventional arms reduction talks similar to CFE. Inspection teams in airplanes could try to count, identify (by remotely reading tags or sensors), and document legal TLIs, as well as search for covert ones. (By looking for illegal TLIs, the overflights could help deter their very construction.) Discovery of unusual activities or objects could be used to target suspect-site inspections or cue NTM. Tethered aerostats could temporarily monitor the perimeter of an OSI site for illegal movements while preparations were made for an inspection or until a ground perimeter could be established. Similarly, restrictions on military force movements, deployments, and exercises could be observed from the air.

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[23] Smithson and Krepon, op. cit., footnote 21, pp. 15 and 18-25.

[24] Ibid., p. 24-25.

[25] Conceivably, some rare precursors or byproducts could be banned along with their warfare product.

[26] For a discussion of on-site inspection types, benefits, and costs, see: U.S. Congress, Office of Technology Assessment, *Verification Technologies: Measures for Monitoring Compliance With the START Treaty—Summary*, OTA-ISC-479 (Washington, DC: U.S. Government Printing Office, December 1990).

Regional warning and confidence-building agreements might also involve aerial surveillance in order to add stability to and reduce tensions in some of the world's hot spots (e.g., the Korean Peninsula, South Asia, and the Middle East). Furthermore, aerial surveillance could be used by United Nations peace-keeping forces to extend their ability to observe and document (and thus deter) violations of the terms of United Nations involvement (e.g., a cease-fire agreement).[27] Aerial surveillance has already been used in similar circumstances in Yemen and the Sinai.[28] In the case of the Sinai, since 1974 American and other reconnaissance aircraft (airplanes and helicopters) have helped to ensure compliance with demilitarized and force-limited buffer zones between Israeli and Egyptian forces. They have also periodically undertaken surveillance of sites prior to ground inspections.[29] Mutual aerial mapping ventures might also provide the basis for settling disputed borders.

Beyond the military arena, airborne chemical and radiation detectors could be employed cooperatively to measure pollution or radiation levels as part of a regional or international prohibition or cleanup effort.[30]

Finally, one of the more unusual ideas for aerial surveillance is the plan of one company to lease to television networks an airplane equipped with side-looking airborne radar (SLAR), infrared, and low-light TV sensors, and film-editing facilities.[31] This commercial airplane could cover fast-breaking news events globally in a way previously only enjoyed by the superpowers. Thus, aerial surveillance might not only take the virtual monopoly on overhead monitoring away from the superpowers and give it to other states,[32] but it might take away from governments in general.

Conclusion

A wide variety of agreements that require monitoring or confidence building could take advantage of sensors on aircraft. Yet, just because cooperative overflights might have some utility does not mean that they are necessarily the best choice for the job. As was discussed in chapter 2, aerial observation is not cost-free, nor does it always have unique qualities that can not be provided by some other means, especially NTM or OSI. The choice of one type of monitoring measure or combination of measures depends on many factors, including the capability of each measure, the robustness of NTM, the degree of cooperation between the negotiating parties, the political advantages of open cooperation, the intrusiveness of the measure, and financial costs. Aerial surveillance is not a panacea; it may be a useful tool.

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[27] See Michael Krepon and Jeffrey P. Tracey, " 'Open Skies' and UN Peace-Keeping," *Survival*, vol. XXXII, No. 3, May/June 1990, pp. 251-63.

[28] Allen V. Banner, "Overhead Imaging for Verification and Peacekeeping: Three Studies," Canada, External Affairs and International Trade, Arms Control Verification Occasional Papers No. 6, March 1991, p.29.

[29] Brian S. Mandrell, *The Sinai Experience: Lessons in Multimethod Arms Control Verification and Risk Management*, Arms Control Verification Studies No. 3 (Ottawa, Ontario, Canada: Canadian Department of External Affairs, 1987), pp. 5, 8, 13, 17, 22, 25, 45.

[30] WU-2A aircraft, variants of the U-2, were dispatched in the late 1950s and early 1960s to sample at high altitude the spread of nuclear debris following tests. David Donald, *Spyplane* (Osceola, WI: Motorbooks International, 1987), p. 29.

[31] *Aviation Week and Space Technology*, "Upscale Eye-in-the-Sky," Aug. 20, 1990, p. 13.

[32] For countries that do not have extensive NTM capabilities, aerial surveillance fills an informational void that previously could only be filled by one of the superpowers. This leads to the philosophical question of whether it is in the superpowers' own national security interest to negotiate away their near monopoly on overhead reconnaissance in exchange for the principle of enhanced regional or international security.

Chapter 6

BROAD AREA SEARCHES FOR ARMS CONTROL TREATY VIOLATIONS

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Chapter 6

BROAD AREA SEARCHES FOR ARMS CONTROL TREATY VIOLATIONS

Summary

Congress can reasonably expect quantitative assessments of the uncertainties inherent in arms control treaty verification. While such assessments are often provided, witnesses need to be clear about the assumptions and methods (if any—some quantitative statements are hunches or figure of speech, not a bad thing as long as the recipients understand the spirit in which the statements are made) by which they reach their assessments.

The arms control efficacy of aerial monitoring—whether as an anomaly detector, a violation deterrer, or a confidence builder—rests on the search capabilities of the aircraft and their associated equipment. Searches such as those entailed by aerial monitoring can be analyzed mathematically: simplistic analysis suggests that relatively heavy aerial monitoring alone would probably find some types of arms control treaty violation, if present, in a year. **Refinement of the analysis shows that considerable *prior information*—clues about where to look and for what—will be needed if aerial monitoring is to make a significant contribution to arms control verification.**

Introduction

The use of cooperative aerial surveillance in arms control agreements may be its most important task. Not only might overflights tend to build confidence in an accord, but aerial monitoring flights may fulfill a search, warning, inspection, cost-raising, or deterrent function by observing compliance with specific provisions of an agreement. Information from monitoring can also be used to support other verification methods, particularly on-site inspections (OSIs).[1] For example, aerial surveillance in an arms control context might:

- observe military exclusion zones or disputed borders to deter, detect, and warn of the illegal presence of restricted forces;
- inspect conditions at declared bases or facilities to observe compliance, to monitor movement or other restrictions, or to assess the need for and prepare for an OSI;[2]
- confirm the destruction of declared facilities, equipment, or weapons;
- search for indications of noncompliance that require other methods of verification for final confirmation;
- by virtue of an increased chance of detection, force a cheater to expend more effort and money to violate the treaty or deter him or her completely;[3] or
- search for treaty violations distributed over some large area being surveyed.

This chapter applies a quantitative search analysis method to the last role, searching large areas for violations. Focusing on this one mission will serve several useful purposes. First, it will allow us to illustrate how quantitative methods can be applied to the larger problem of estimating confidence levels in our ability to find arms control treaty violations if they exist. Second, the analysis shows how comparisons could be made among various monitoring options to produce more cost-effective monitoring regimes. Third, examining the potential and limits of aerial search underscores the importance of applying multiple, complementary instruments to monitoring tasks.[4]

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[1] The various utilities of aerial surveillance are discussed in detail in ch. 2.

[2] For example, sensor information and photographs might be used to create a map of the site and indicate the most important locations to inspect. Amy Smithson and Michael Krepon, "Strengthening the Chemical Weapons Convention Through Aerial Monitoring," Occasional Paper No. 4, The Henry L. Stimson Center, Washington, DC, April 1991, pp. 14, 21-22.

[3] Ibid., p. 3. Amy Smithson and Michael Krepon state, "Aircraft overflights could marginally increase deterrence if approved flight plans and sensors increase the likelihood of detection or the possiblility of follow-up investigations."

[4] Note that aerial warning is closely related to aerial search and that many of the same lessons apply.

Quantification

Congressional demand exists for quantification of answers to questions regarding compliance,[5] though the urge to quantify verifiability is not universal.[6] The expression, in the Intermediate-Range Nuclear Forces (INF) Treaty hearings, of such matters in round numbers suggests that Members and witnesses understand that great precision is neither possible nor needed. However, testimony and colloquy in the INF case also indicate an absence of consideration of important factors which should enter into an assessment—quantitative or otherwise—of the verifiability of a treaty: the length of time allowed for detection of the violation, the difference between verifying compliance with the treaty as a whole and verifying compliance with any one subset of its provisions (e.g., in the INF case, those pertaining to SS-20s), the significance of the violation, and the difference between the probability of detecting the presence of a covert force and the probability of detecting any single missile therein.

Congress needs to decide how much to invest in verification measures, and quantitative analysis can indicate how much additional confidence might be obtained as a benefit of increased spending. This report discusses the quantifiable aspects of aerial search at some length, not only for their own sake, but as a good example of certain statistical issues arising in treaty verification. Inasmuch as most verification assets, especially those subsumed under the heading national technical means'' (NTM) of verification, monitor more than one treaty at once, a complete analysis of treaty verification would simultaneously embrace all treaties and all verification assets. The simple examples explored in this report are thus intended as models for discussion and analysis, not as the last word on the utility of aerial search.

Even if one does not resort to quantification when interpreting data from aerial search flights, an important lesson of the approach we will examine—that lack of evidence must be interpreted in light of the likelihood that evidence would have been obtained were it to exist—retains its validity.

The Limitations of Aerial Search

As discussed in chapter 3, the aerial monitoring provisions of particular treaties will set limits on the number of flights, their duration, the equipment that may be carried, and the freedom to fly anywhere at any time. These constraints limit the effectiveness of aerial monitoring. Even without them, however, aerial monitoring would remain subject to certain limitations inherent in most treaty-monitoring or intelligence-gathering means.

The most general trait of these limitations is the everyday finding that we notice things far more readily if we are looking for them. Treaty-monitoring efforts to date show distinct signs of this limitation: for example, the monumental radar near Krasnoyarsk (a treaty-limited item (TLI) of the Anti-Ballistic Missile (ABM) Treaty) went unnoticed for many months despite its detectability by NTM, because the managers of NTM had no reason to examine its particular locale for SALT I TLIs.[7] In another example, efforts to find and destroy Iraqi Scud launchers during the Persian Gulf War were impeded by the use of launchers other than the expected Soviet-made transporter-erector-launchers (TELs). These examples and others suggest that aerial monitoring may be most efficiently applied if specialized: such specializations might include the monitoring of declared deployments or the inspection of particular locations. When used more generally, aerial search (like any other means of collection) benefits greatly from the use of *prior information* as to where to look and for what to look (a point addressed more fully below)

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[5] Witnesses and Senators in the hearings on the Intermediate-Range Nuclear Forces Treaty variously stated that the ''intelligence community . . . put the potential for verifying compliance somewhere in the 10-or 20-percent region,'' that ''the chances of the United States detecting covert SS-20's is [sic] about 1 in 10,'' that ''we can detect 1 in 10'' SS-20s, that therefore if ''we suddenly detect 5 [SS-20s], . . . the Soviets could have a viable force of up to 50 in hiding,'' that ''given the entire verification package, including national technical means, . . . we have high confidence in the ability to verify the provisions of the treaty,'' and that ''high confidence'' means ''well above 50 percent.'' (See U.S. Congress, hearings before the Senate Foreign Relations Committee, *The INF Treaty*, 100th Cong., 2d sess., Part 3, p. 35; Part 5, pp. 86-96 *passim*.)

[6] Another witness at the same hearings contested the claim that the intelligence community had produced the the 10- to 20-percent figure on the grounds that the intelligence community does not assess verifiability at all, and does not express estimates in terms of percentages. The witness also stated that the U.S. Arms Control and Disarmament Agency would not use percentage terms either. (Manfred Eimer, Assistant Director of the Bureau of Verification and Intelligence, U.S. Arms Control and Disarmament Agency, Ibid., Part 5, p. 96.)

[7] Malcolm Wallop and Anthony Codevilla, *The Arms Control Delusion* (San Fransisco, CA: ICS [Institute for Contemporary Studies] Press, 1987), p. 65.

Box 6-A—Search Effort, Width, and Rate

The following example introduces the concepts of search effort, search width, and search rate.

Consider a 1-hour search for mobile missile launchers, conducted from an aircraft flying at 200 miles/hour. The *effort* devoted to the search is the hour of flying; the output will be the number of launchers spotted.

For simplicity's sake, we will make the assumption (soon to be dropped) that the vision of the observers and equipment in the aircraft operates in a completely deterministic fashion: they see any launchers within 2.5 miles of the airplane's ground track. If we knew a priori that launchers inhabit the territory with a density of one launcher per hundred square miles, we would expect that an hour of searching would discover 10 launchers. The aircraft will examine a swath 200 miles long by 5 miles wide for a total of 1,000 square miles, and

200 miles × 5 miles × .01 launchers/square mile = 10 launchers.

If we were uncertain as to the capabilities of the observers but knew a posteriori that they had seen ten launchers, we could view this result as confirmation of their stated capability to examine the territory 2.5 miles to either side of the airplane:

10 launchers seen @ 0.01 launchers/square mile = 1,000 square miles seen

and

1,000 square miles/200 miles flown = 5 mile "sweep width."

Relaxing the assumption of deterministic sighting, let us suppose that we recognize that luck will play a role in the sighting of missile launchers—some launchers near the ground track of the airplane will be overlooked, while others located a distance away will be spotted by chance. Still aware that launchers have been spread out at an average density of one per ten square miles, we discover that 10 launchers have been sighted and interpret the result to mean that the crew and equipment can see an *average* of 2.5 miles away from the airplane. We will therefore say that the aircraft has an *effective sweep width*[1] of 5 miles, computed by the two equations above. This width, multiplied by the speed of the aircraft, leads to the *sweep rate*: 1,000 square miles/hour.

The effective sweep width is related to, but different from, the *theoretical sweep width*—the width of the swath in which the sensor *could* detect a target. The effective sweep width cannot possibly be greater than the theoretical sweep width, and is likely to be considerably less. The disappointingly low ratio of the effective sweep width to the theoretical sweep width was one of the first findings of the investigation of aerial search for German submarines in the Second World War. Even after discounting the theoretical sweep width in proportion to the fraction of the time that U-boats spent submerged, a factor-of-two discrepancy remained, explicable only in terms of human factors.[2]

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[1] Called operational sweep width in the search theory literature.

[2] Philip Morse and George Kimball, *Methods of Operations Research* (Washington, DC: Department of the Navy, 1946), p. 43.

Most important, monitoring is more effective when multiple means of monitoring can be used to cue one another. (The second part of this chapter addresses this point.) Aerial monitoring would thus rely on other monitoring methods, e.g., OSI and NTM, but this reliance ought not to be construed as a defect, because the other methods would rely on aerial monitoring in turn.

This chapter begins with an introduction to search theory; it then offers concrete examples of the application of that theory to hypothetical aerial searches for Soviet SS-24 and SS-25 intercontinental ballistic missiles, missiles that would be limited under the proposed Strategic Arms Reductions Talks (START) Treaty.[8]

"Search as an Operation in Practical Life"[9]

Reflection on our everyday experiences of search reveals some important characteristics of searches:

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[8] Aerial surveillance is not contemplated for inclusion in the START Treaty, and Open Skies surveillance is not officially linked with arms control treaty monitoring as such. Nevertheless, the question of how Open Skies-like surveillance would perform in searches for these START TLIs is an instructive one to answer.

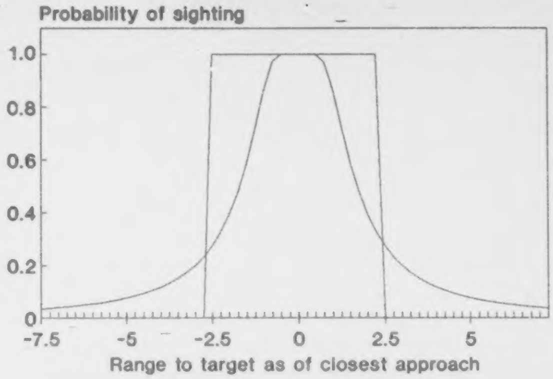
[9] Bernard Osgood Koopman, a pioneer in the mathematical development of a theory of search, used this phrase as a section heading in his book. (Bernard Osgood Koopman, *Search and Screening* (New York, NY: Pergamon, 1980), p. 12.)

Box 6-B—Lateral Range Curves

The "sweep width" assessment of search effectiveness merits some scrutiny. It seems plausible in a bottom-line sense: the searcher has spotted as many launchers as it would have if it could see perfectly out to the 2.5-mile limit and not an inch beyond. Moreover, the crew has missed a launcher within 2.5 miles for each that it spotted beyond 2.5 miles. Thus the interpretation of 2.5 miles as an average[1] spotting distance is reasonable and useful, even though it treats all sightings as occurring when the launcher is directly abeam of the airplane, which is certainly not the case: many targets, perhaps all, will be detected some time before or after they pass abeam of the aircraft.[2] Keeping track of the targets according to their distance when they pass abeam of the aircraft is, however, a useful accounting convention, according to which we can form a *lateral range curve*, plotting the probability that a launcher is spotted as a function of its distance from the ground track of the airplane.

The lateral range curve contains far more information about the characteristics of the searcher than does the sweep width. In particular, it keeps explicit the point that, given an imperfect searcher, no amount of searching can guarantee that a target will be found. The "effective sweep width" characterization of the imperfect search of a broad width as a perfect search of a narrower width can give a misleading impression of how the efforts of many such searchers (or the repeated efforts of one such searcher) combine: the temptation to take the sweep width concept literally and imagine a lawn spreader-like application of perfect search to the region of interest must be avoided. Mathematically correct ways of assessing searchers' combined or repeated efforts exist and will be presented below. The sweep width, however, retains its utility as a one-number figure of merit suitable for use in practical calculations.

Lateral Range Curve and Equivalent "Cookie-Cutter"



The arch-shaped lateral range curve depicts the probability that the target will be detected as a function of the searcher's distance of closest approach. There is some chance that nearby targets will be missed and, conversely, that a distant target might be seen. The rectangular curve represents a "cookie-cutter" deterministic lateral range curve, guaranteed to see the target if it passes within 2.5 miles and to miss it otherwise. The two curves are equivalent in the sense that, assuming a random distribution of targets, each searcher will detect the same number.

SOURCE: Office of Technology Assessment, 1991.

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[1] In the sense that calculation based on the use of this fixed distance would result in the same number of sightings as are actually experienced.

[2] The ranges at which such launchers get spotted are thus underestimated.

the role of luck, our ability to make statements about the difficulty of the search, the utility of coordination of the search effort in the (usual) case that it is performed by more than one searcher, and the question of efforts on the part of the target to stay hidden. (See also box 6-A.)

Luck plays two major roles. In the case of a search for a moving target, e.g., an escaped pet, the searcher and the target move about in the same area and only encounter one another by chance. Even in the case of a stationary target, e.g., a mislaid set of keys, the searcher might approach the keys very closely without finding them, perhaps later exclaiming, "But I looked right there!" when somebody else locates the keys. The first example shows the role of luck in bringing a searcher-target encounter about; the second shows the role of luck in determining whether an encounter results in a sighting. (See also box 6-B.)

The role of chance notwithstanding, assessments of a search's difficulty or likelihood of success can be made in advance. A set of keys misplaced somewhere in the house is one thing; a contact lens lost during a fast break on the basketball court is quite another. The likely outcome of the search is determined by the effectiveness of the searcher (how good he or she is at searching), and by innate characteristics of the target of the search, the size of

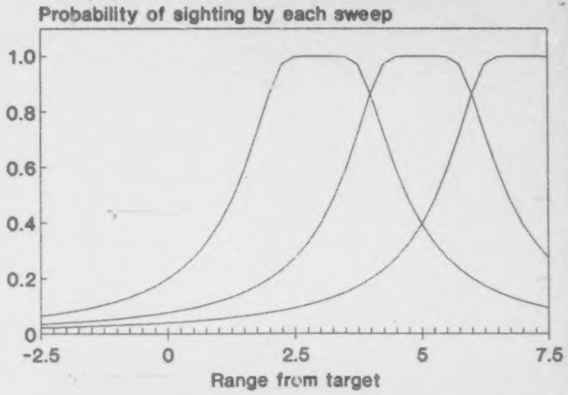
Box 6-C—Coordination of Search Efforts

Suppose that we wish to use airplanes of the type considered in boxes 6-A and 6-B to sweep a 5,000 square mile region clean of treaty-banned missile launchers.[1] The effort required would thus seem to be the searchable area divided by the sweep rate:

5,000 square miles ÷ 1,000 square miles per hour = 5 hours.

This calculation (despite its dismaying implications for a Soviet Union of roughly 6,500,000 square nautical miles) is, in fact, overoptimistic. The reason becomes apparent when we try to decide on the correct search pattern to fly: despite the 5-mile sweep width, simply spacing adjacent sweeps 5 miles apart won't do because the 2.5-mile sighting range is an average, not a guarantee. Five-mile spacing is good (apart from any exploitation of terrain and or other prior information), but not good enough: in fact, the non-deterministic nature of the search ensures that no search pattern or allocation of search effort can be certain to see all targets. Given the notional lateral range curves shown here, for example, the target has an 88-percent chance of being missed by the sweep that passes 2.7 miles away, a 92-percent chance of being missed by the sweep that passes 5 miles away, and a 96-percent chance of being missed by the sweep that passes 7 miles away, for a combined 78-percent (0.88 × 0.92 × 0.96) probability of being missed completely and thus a 22-percent chance of being sighted.

Sighting by Successive Sweeps at Ranges of 3, 5, and 7 Miles From Target



Like crop-dusters, searchers can coordinate their flights so as to compensate for a somewhat uneven application of search effort. These overlapping lateral range curves show how even distant passes contribute to the overall probability that the target will be detected.

SOURCE: Office of Technology Assessment, 1991.

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[1] That is, for missile launchers obligingly left out in the open. Later we will take up the question of searching for targets that might be concealed.

the region in which the target is located, the search effort available, the presence of any prior knowledge as to the target's whereabouts, and how well the search effort is coordinated.

Multiple Searchers and/or Targets

Coordination of the search effort can help a great deal if the amount of search effort available is comparable to that needed for a complete search of the region of interest. A dragnet search, perhaps for a child lost in the woods, is conducted with searchers walking shoulder-to-shoulder—clearly a superior approach to the uncoordinated alternative of simply turning the same number of searchers loose in the woods for the same amount of time. Coordination ensures that no location goes unsearched while another is oversearched. (In the lost-child example, coordination can also ensure that the child does not wander from an area that has not been searched into one that already has. See also box 6-C.) If only meager search resources are available, no amount of coordination can confer a high probability of success; a plethora of searchers, on the other hand, can do a good job without particularly coordinating their efforts. (See also boxes 6-D and 6-E.)

Thus far we have assumed that the searcher seeks a unique target. Many searches, however, would be satisfactorily concluded if they were to find any single target out of a large population. For example, a hungry cat searching for mice is not particular as to which mouse it catches. Similarly, many would consider the search for treaty violations to end if even one violation were found, inasmuch as that is

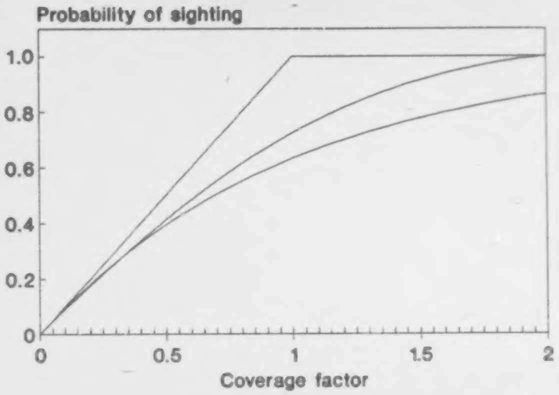
Box 6-D—Coverage Factor

Detailed lateral range curve information such as that used in the example is rarely available: an analyst is likely to be asked what to make of a given search situation given only the search effort, an estimate of the sweep rate and perhaps a rough idea of the shape of the lateral range curve. In this situation, the analyst can state some bounds on the probability that a given target will be sighted. Each starts with the *coverage factor*, the product of the search effort and the sweep rate. This quantity can be thought of as the number of square miles searched: the question is how these square miles are applied to the square mileage of the territory to be searched. In the case at hand, the coverage factor is equal to unity.

The upper bound is that given by the optimistic calculation cited above: 100-percent probability of sighting the target given 5 flying hours of effort, a 5-mile sweep width, a 200-mile/hour speed, and 1,000 square miles of searchable area. This upper bound treats the 5-mile sweep width as a guarantee instead of as an average, and assumes that the airplane can fly so as to search every point in the searchable region: 1,000 square miles' worth of searching have been laid neatly, like 5-mile-wide wallpaper, on 1,000 square miles of territory.

The lower bound, recognizing that the 2.5-mile sighting range is a mathematical construct[1], assumes that the 1,000 square miles' worth of search effort are laid down like confetti instead of like wallpaper. Absent any assumption that the pilots are intentionally suboptimizing the search, this assumption of a completely haphazard search results in the lowest possible value for the probability that a target will be detected because it gives the searchers no credit for organizing their efforts. Some parts of the region are oversearched at the expense of others. In the case at hand, with 1,000 square miles' worth of coverage factor distributed confetti-style on 1,000 square miles of searchable region, a target has a 63-percent chance of being sighted. Doubling the coverage factor would raise the probability of detecting a target to 86 percent.

Probability of Sighting as a Function of Coverage Factor



Perfect coordination of completely deterministic sighting would lead to a sighting probability (as a function of the coverage factor) shown by the upper curve. Completely haphazard application of search effort leads to a sighting probability shown by the lower curve. Real-world cases often lie near the curve in between: note that 100-percent coverage does not, in such cases, guarantee a sighting.

SOURCE: Bernard Osgood Koopman, *Search and Screening* (New York, NY: Pergamon, 1980), p. 78.

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[1] Reflecting, again, the fact that as many targets are sighted beyond that range as are missed within it.

all that is required to brand the other side as a treaty violator.[10]

Treatment of Target Concealment

Many—if not most—INF, START, and Conventional Armed Forces in Europe (CFE) TLIs, e.g., airplanes, mobile missile launchers, and tanks, could be driven into buildings, caves, or tunnels and thus hidden from aerial searches.[11] In fact, these treaties allow concealment according to normal operational procedures. For example, mobile missile launchers can be camouflaged, even though fixed silos cannot be, because camouflage is customary for military vehicles. Is aerial search then useless for assessing compliance with these treaties?

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[10] The ultimate sanction against a country caught cheating would be abrogation of the treaty itself. The United States prepared a contingency plan for the resumption of atmospheric testing in the event of a Soviet breach of the Limited Test Ban Treaty. (Michael Krepon, *Arms Control—Verification and Compliance*, headline series No. 270 (New York, NY: Foreign Policy Association, 1984), p. 16.) Henry Kissinger saw the consequences of a revealed violation as spilling over from treaty to treaty: "Any country that contemplates a rupture of the treaty or a circumvention of its letter and spirit must now face the fact that it will be placing in jeopardy not only a limited arms control agreement, but a broad political relationship." (Quoted in Wallop and Codevilla, op. cit., footnote 7, p. 89.) Historically, recourse to treaty abrogation in the event of violation has rarely, if ever, been carried out when an instance of violation has been discovered.

[11] For a treatment of camouflage, concealment, and deception, see ch. 3.

Box 6-E—Use of Imaging Systems in Concert

Clearly the chance of detecting a target is improved if additional imaging systems are brought to bear. The question is best addressed through the paradigm of lateral range curves and sweep widths. Indeed it is in this sort of calculation that the sweep width comes into its own as a simple and useful one-number summary of the searcher's efficacy.

Suppose that a visible-light photography system records a 4-mile swath with, after interpretation is complete, an 80-percent chance of detecting a treaty-limited item (TLI) within that swath; suppose further that a synthetic aperture radar records an 8-mile swath but, because of a lower resolution, has only a 40-percent chance of seeing TLIs within that swath. (Note that each of these systems has a 3.2-mile sweep width.) We wish to know the combined effect of the two systems, i.e. the effective sweep width of an airplane carrying both.

A target within the camera's field of view has a 20-percent chance of being missed by the camera and a 60-percent chance of being missed by the radar. Thus, assuming that detection by one system is statistically independent of detection by the other,[1] it has a 12-percent (because $0.2 \times 0.6 = 0.12$) chance of being missed by both, for a complementary 88-percent chance of being detected by one or the other or both. The two 2-mile strips to either side of the camera's field of view are seen only by radar, with its 40-percent chance of detecting a target therein. Therefore the combined sweep width of the two detectors is

$$2 \times 0.4 + 4 \times 0.88 + 2 \times 0.4 = 5.12 \text{ miles.}$$

This is a considerable improvement over the 3.2-mile sweep width offered by either system alone, but somewhat less than the 6.4-mile sweep width which one might naively have thought would result from their combination.

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[1] This assumption makes sense if the main source of detection uncertainty for targets within the two systems' fields of view is the interpretation step. These interpretations will be conducted separately, and probably by different people. If actual target characteristics, e.g. orientation, contribute to the probability of not being seen, then the assumption of independence would break down. There is reason to think that orientation has little to do with probability of detection (see Koopman, op. cit., footnote 9) and we may note for the present example that many other target characteristics, e.g. relative brightness compared to the background, will be different for the two systems and thus unlikely sources of correlation between the two detection probabilities. Lack of correlation would itself be a desirable quality for candidate pairs of detection mechanisms; inverse correlation would be even better, because with inverse correlation each sensor would be especially good at seeing the targets with respect to which the other sensor was especially bad.

Of course, aerial searches might still see the buildings, tire tracks leading to caves, and so on, so that suspicions could be aroused even if no actual violations were perceived during the flight. In this way, the overflights could aid other inspection procedures allowed for in the particular treaties, including the use of NTM.

Nevertheless, one might suppose that a system of deliberate TLI concealment, even one that worked well, would not work perfectly. The scramble (perhaps nationwide, depending upon the treaty protocol implementing the aerial search proposal) of the TLIs for cover when an overflight was announced would on occasion be marred by some units not getting the word, units breaking down on their way to the concealment facility, and so on. Thus deliberate concealment measures could degrade the performance of the overflights, but not necessarily vitiate them completely. (See also box 6-F.)

Simple Aerial Monitoring Calculations: Aerial Search for SS-24 ICBMS

The Soviet SS-24, a rail-mobile intercontinental ballistic missile (ICBM) physically comparable to the U.S. Peacekeeper, is powered by solid fuel and delivers 10 reentry vehicles.[12] Unlike the proposed rail-mobile version of the Peacekeeper, SS-24s frequently deploy to the rail net in peacetime. The Soviet Union has over 145,000 kilometers of track to which SS-24 can deploy.[13] This figure overstates the difficulty of finding the SS-24 because it includes considerable amounts of dual trackage (though not as great a proportion as would be found on other rail nets, e.g., that of the United States). A more accurate figure for the total amount of *roadbed*

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[12] U.S. Department of Defense, *Soviet Military Power 1990* (Washington, DC: U.S. Government Printing Office, 1990), p. 52.

[13] *World Factbook 1990* (Washington, DC: U.S. Government Printing Office, 1990), p. 217.

Box 6-F—Treatment of Deliberate Target Concealment

Deliberate target concealment, like any other degradation of search effectiveness, can be characterized mathematically as a reduction (perhaps a very large reduction) of the aircraft's sweep width. For example, if each TLI had a 99-percent chance of reaching cover when bidden to do so, an aircraft with a 3.2-mile sweep width would find its width reduced to 0.032 miles. That is to say, an aircraft with a 4-mile wide photographic field of view, backed up by a staff which finds 80 percent of the TLIs present in the photographs would—if confronted by an opponent who successfully concealed his TLIs 99 percent of the time—see on the average as many TLIs as an aircraft which exerted perfect scrutiny, with no possibility of concealment, on a strip 0.032 nautical miles (or about 200 feet) wide.

The above statement should not, of course, be construed as a (ludicrous) statement that concealment measures somehow restrict the camera's field of view to a narrow strip; to reiterate, concealment lowers the number of targets seen to that which would be seen if scrutiny were perfect and the field of view were so narrowed. In fact, of course, the scrutiny is imperfect (with much of the imperfection introduced by the targets' concealment), and the field of view is much wider. The narrow strip, however, proves to be a useful mathematical construct, as will be seen below.

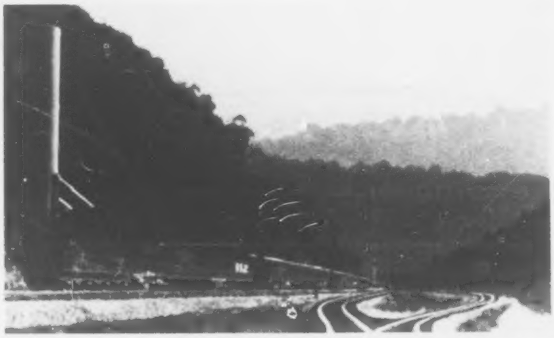

Photo credit: U.S. Department of Defense

Artist's conception of rail-mobile SS-24 missiles on maneuvers in a dual-tracked section of the Soviet railroad system.

in the USSR would be 100,000 kilometers, or 68,000 nautical miles. Moreover, logistical and communications considerations may constrain the SS-24 force from using the entire rail system.

An aerial search by a single vehicle could perhaps overfly 3,000 nautical miles of roadbed, suggesting a 4-percent (i.e., 3,000 divided by 68,000) chance of seeing *any particular* SS-24 train. If mobile ICBMs were completely banned by some arms control agreement, this simple calculation suggests that each flight's chance of detecting a violation would be roughly 4 percent *per deployed train*.[14]

Most refinements to the above simplistic calculation—other than those modifying the assumption that the search is performed by an unassisted aircraft—tend to lower the estimated probability of finding a violation. (See also box 6-G.) For example, not all extant trains would be deployed at all times, and the aerial search task is complicated by the presence of ordinary trains—perhaps one every 50 miles.[15] The missile-carrying trains would have to somehow be discriminated from the ordinary trains, and caution about accusing the Soviets of a violation would introduce a benefit-of-the-doubt effect by which some SS-24 trains could escape identification. These considerations could lower the flight's chance of finding a violation from 4 percent per train to 2 percent overall.

With 10 warheads per missile and more than one missile per train, and in an environment of reduced strategic arsenals, only a handful of trains would be needed to constitute what could plausibly be deemed a militarily significant force. If considerations such as those raised in the preceding paragraph were to lower the overall chance of finding a violation to 2 percent per flight, 50 flights (nominally a year's worth) would have only a 63-percent chance of finding a violation even if they were all dedicated to the search for illegal rail-mobile missiles.

Simple Aerial Monitoring Calculations: Aerial Search for SS-20 IRBMS and SS-25 ICBMS

The SS-20 is a three-warhead, intermediate-range ballistic missile (IRBM), deployed on land-mobile launchers by the Soviet Union. It is an item banned

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[14] The chance of finding at least one out of n trains is $1 - 0.96^n$. For small values of n, $1 - 0.96^n$ is about equal to $0.04 \times n$.

[15] Based on *World Factbook 1990*, op. cit., footnote 13, figures for total trackage and total ton-miles hauled, and some estimates of train speed, number of cars, and tons per car.

Box 6-G—Calculation of Sighting Probabilities

This box explains how overall sighting probabilities can be calculated given the search effort, the size of the region to be searched, and an assumption about how the search effort is organized. These probabilities result from consideration of the problem in terms of the Poisson probability distribution, whose density parameter *p* is the coverage factor, sweep rate times effort per area searched. The probability of a target being sighted *n* times is then $p^n e^{-p}/n!$. Substituting $n = 0$ gives the probability e^{-p} of the target not being sighted at all, for a complementary probability $1-e^{-p}$ of it being sighted.

The upper bound for the probability of sighting, then, results from considering the search as perfectly coordinated and is the coverage factor or unity, whichever is the lesser:

$$\mathrm{P(sighting)} = \min\ (\text{coverage factor}, 1).$$

The lower bound results from considering the search as splattering coverage over the searchable area confetti-style:

$$\mathrm{P(sighting)} = 1 - e^{-\text{coverage factor}},$$

The truth will lie somewhere between these two extremes. Differing assumptions as to exactly how well the searchers can coordinate their efforts lead to differing values for the probability that a target will be sighted as a function of the coverage factor. One commonly used function is

$$\mathrm{P(sighting)} = \mathrm{cnorm}(\text{coverage factor}),$$

where "cnorm" represents the cumulative normal distribution. This (rather startling) appearance of the cumulative normal distribution can be derived from a widely applicable expression for probability of sighting as a function of true—not lateral—range, and has the advantage of being easily looked up in commonly available tabular form or as a "canned" function on a computer or calculator.

Note that the three functions agree for very small coverage factors and for very large ones: the exact degree of coordination only matters for medium values of the coverage factor because very sparse coverages run little risk of redundant overlapping and very dense ones can afford the wasted effort.

In a case in which the coverage factor is based on an effective sweep width drastically reduced by sensor imperfections or target concealment (see box 6-F), the instances of sighting will be so randomized that the confetti-style equation for probability of sighting should be used.

by the INF Treaty, and the Soviets are obliged under the INF Treaty to destroy their existing SS-20s and not build any more. The SS-25 is a single-warhead, land-mobile ICBM physically comparable to the proposed U.S. Midgetman. Unlike the proposed "garrison-mobile" Midgetman, SS-20s and SS-25s deploy to the countryside in peacetime.

The Soviet Union has 1.6 million kilometers (1.1 million nautical miles) of roads.[16] The SS-25 TEL is billed as off-road-capable, so it would not (except perhaps during mud season) be restricted to the 800,000 miles of hard-surfaced road. However, the SS-25 TEL is not considered to be *as* off-road capable as the proposed U.S. Midgetman TEL. We might therefore assume that operational SS-25s would operate on unimproved roads and even off the road, but would not stray far from the road. A simplistic calculation would then suggest that a 3,000-nautical-mile flight would have a 0.37-percent (i.e., 3,000 divided by 1.1 million) chance of seeing a particular SS-25.

Refinements to this calculation include consideration of the fact that more than one section of road would be visible at a time, raising the probability of detecting the launcher. Other refinements, like those suggested above in the case of the SS-24, reduce the estimated probability of seeing a launcher: not all launchers are out of their garrisons at any one time and the reluctance to cry "wolf" at the sight of any large truck with a cylindrical cargo would tend to mask some actual sightings. In particular, aerial search for illegal SS-20s would be greatly complicated by the presence of legal SS-25s, whose launchers are outwardly similar. Chances of finding any particular illegal SS-20 or SS-25 on a road would be worse than those of finding a particular rail-mobile SS-24. Compared to the SS-24, the small number of warheads per missile on the land-mobile systems would require that 10 times as many be

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[16] *World Factbook 1990*, op. cit., footnote 13, p. 217.

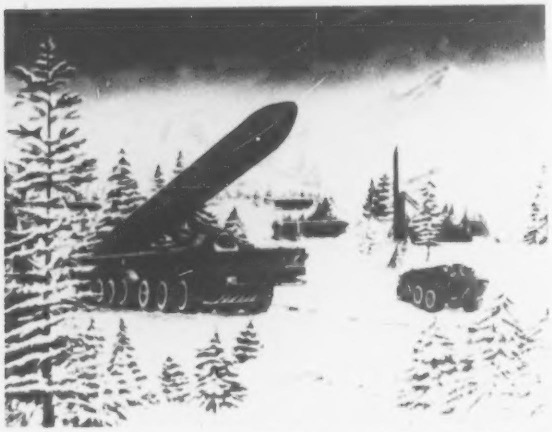

Photo credit: U.S. Department of Defense

In an artist's conception, road-mobile SS-25 ICBMs take to the field in a remote area of the Soviet Union. The mobility of such systems increases their survivability, but also complicates verification of any numerical limits placed on them.

deployed to reach a given level of military significance. However, the lower chance per missile of finding a violation counteracts this effect.

SS-20s and SS-25s can also leave the roads and roam the countryside. The arable land and meadowlands of the Soviet Union total 1.8 million square nautical miles,[17] and another 2.7 million square nautical miles of the Soviet Union is covered by forest. Arable lands and meadows generally support tractors, and thus can be considered capable of supporting the off-road capability of the SS-25 launcher. In addition, these launchers could penetrate the forested and mountainous regions of the Soviet Union[18], as well as operating on nonarable tundra, even if they could not negotiate each and every square meter of such territory. Thus one might credit the SS-25 with creating an "uncertainty area" of at least 5 million square nautical miles.[19] (The entire landmass of the Soviet Union is about 6$^1/_2$ million square nautical miles.) The calculations performed in the previous chapter thus apply roughly to this case: an overflight might see, on the average, a mile-wide swath throughout its 3,000-mile flight, leading to a 0.06-percent chance per missile that a single flight would find a violation.

As will be discussed later, knowledge of Soviet infrastructure could help. For example, there might not be enough bases to serve TELs spread out over the whole 5 million square nautical miles, in which case the inspections could concentrate on regions near bases.

Discussion

Many important considerations do not appear in the simple calculations described above. A more complicated calculation could take these into account, but for now we will simply point them out. Some make the calculation look pessimistic while others make it look optimistic. (See also box 6-H.)

For example, the inspecting side would not necessarily know which mode of violation the violating side had chosen, and would thus not know whether to concentrate a year's worth of flying on road, rail, or countryside search. Effort would be diluted by the need to address all of these regions. Other searches would be required too: for example, the 4,530 usable and 2,360 nonusable airfields of the Soviet Union[20] would provide cover and some amount of infrastructure for deployment of mobile ICBMs, and examination of these airfields would use up flying time which might otherwise be allocated to searching roads, rails, or countryside. Finally, a breakout deployment would occur gradually over a period of time (perhaps a year). At the beginning of that period the force is very small, and thus almost impossible to detect; only at the end of the period is the force of the "militarily significant"

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[17] Ibid., p. 216.

[18] They are depicted operating in rough wooded country in U.S. Department of Defense, *Soviet Military Power 1988* (Washington, DC: U.S. Government Printing Office, 1988), p. 47.

[19] Attempts to define an "equivalent uncertainty area" of a road network or otherwise deal with the problem of searching a combination of two-dimensional and one-dimensional regions (e.g., fields and roads) have in general been disappointing because the equivalency depends upon whether or not multiple roads can be captured in the same view, and thus upon what sensor is in use.

[20] *World Factbook 1990*, op. cit., footnote 13, p. 217.

Box 6-H—Satellites v. Aircraft

Because satellites pass over so much territory so frequently, as compared to aircraft, one might wonder whether they would be cheaper platforms for overhead surveillance. An analysis shows that this is not necessarily the case.

One may compare the $10/square mile figure for airborne photography (see in box C-F) with the costs derived for a notional MediaSat newsgathering satellite based roughly on the French SPOT commercial satellite.[1]

MediaSat pictures would cost, all told, from $35,000 to $73,000 each depending upon how various design choices between the austere and the desirable were made and assuming a demand of approximately 1,000 pictures per year. Towards the desirable (and thus more costly) end of the design regime, pictures would each cover an area of 15 by 15 miles and thus cost in the neighborhood of $300/square mile. Thus these pictures cost about 30 times more than their aircraft-obtained counterparts. Their 5-meter resolution is not even close to the resolutions identified as necessary for aerial monitoring of treaties, so one would infer that satellite photography suitable for treaty-monitoring would be even more costly than the MediaSat estimates would indicate.

If the treaty-monitoring effort could benefit by collection of more pictures,[2] economies of scale would make satellites more cost-competitive. While 1,000 15- by 15-mile pictures cover an area comparable to the 50 flights' worth of 5- by 1,000-mile strips we have considered in several examples so far, most of their cost is the investment cost of building and launching the satellite. Extra satellite pictures would be almost free. The investment cost of aerial surveillance, on the other hand, is but a small part of the total, so amortization of that cost over a larger number of pictures would not greatly lower the cost per picture.

Of course, satellite-derived pictures could be worth their extra cost because of other possible advantages of satellites, e.g. more frequent revisit times, than would be allowed to aircraft in a treaty context. One must be careful, however, in drawing facile comparisions between such different systems: where the partisan of satellites points to frequent revisit times, for example, his or her airplane-favoring opposite number points to the greater unpredicability of airplanes' flight plans.

[1] See U.S. Congress, Office of Technology Assessment, *Commercial Newsgathering From Space—A Technical Memorandum*, OTA-TI-ICS-40 (Washington DC: U.S. Government Printing Office, May 1987), especially pp. 25, 39-41.

[2] As might well be the case if many treaties were to be monitored by the same satellite.

size according to which detection probabilities are normally computed, but by then it is too late: the militarily significant force is already in place and there is no time to make an appropriate response.[21]

Concealment, camouflage, and deception (CCD) could all lessen the probability that a TLI would be sighted even if an aerial monitoring aircraft flew by. On the positive side, other arms control monitoring and intelligence sources (as well as cogent use of previous results of aerial monitoring) could provide valuable clues facilitating the air search for treaty-limited objects. Aerial monitoring assets could then concentrate on the most likely regions, increasing their effectiveness. The interplay of CCD and intelligence on the other is quite complex: a study of the search for mobile Scud-B launchers in Iraq would hold important lessons for those who plan to search for illicit SS-20s and SS-25s.

So far we have considered only searches for items totally banned by treaties. START or other treaties might limit, but not ban, such weapons as the SS-24 and SS-25. Aerial search would then need to count TLIs rather than simply look for them. This important topic is treated in appendix A.

The United States and the Soviet Union had at one time reportedly agreed on restricted deployment areas of 125,000 square kilometers (36,400 square nautical miles) for road-mobile ICBMs in a START context.[22] Assuming no wasted effort, a 3,000-nautical-mile flight with a 1-mile sweep width as described above would have a 8-percent chance of seeing any particular TLI. Inspection of the deployment areas is an important minimum requirement, and not an easy one to fill if the aerial monitoring process is supposed to verify a nonzero limit. Nevertheless, it would be a mistake to assess one's inspection capability on the basis of inspections of designated deployment areas. To do so is to run the risk of accepting a verification regime that will work only if the other side does not cheat.

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[21] R. Scott Strait of Lawerence Livermore National Laboratory has pointed out the importance of this ramp-up effect on the detection of breakouts. He has further noted the convenient mathematical fact that, assuming a constant deployment rate, the average detectability of the force is half of the maximum detectablity attained when the force is fully deployed.

[22] Dunbar Lockwood, "Verifying START, From Satellites to Suspect Sites," *Arms Control Today*, vol. 20, October 1990, p. 18.

Simplistic calculations portray a comparatively heavy aerial search schedule as offering only slightly more than even odds of finding a nominally sized treaty violation in a year. Most refinements of these calculations, e.g., consideration of CCD, the difficulties presented by the task of discriminating illicit TLIs from legitimate ones, and the desire to detect a treaty-violating deployment before it is complete, lessen the chances that aerial search will function as hoped. One important consideration, however, has the opposite effect: the use of *prior information* about the TLIs' likely whereabouts—perhaps gained by NTM, or by previous aerial monitoring flights—can focus the attention of the aerial search assets upon those regions most likely to contain items of interest.

Sources and Exploitation of Prior Information

As the preceding sections of this chapter suggest, an aerial search program that had no prior information as to where to look would be an unguided tour or photographic ramble of the target country. It would not be much more focused than the random searches of the GENETRIX project, in which automatic cameras drifted across the Soviet Union beneath weather balloons. (See also box 6-I.) Even complete photographic coverage, were such to be available given treaty constraints, would not provide a practical solution. As we have seen in chapter 3, photographic equipment used in aerial monitoring might resolve a ground sample distance of 6 inches, imaging those 6 inches as a 5,000th of an inch: in that case, the 6.5 million-square-nautical-mile Soviet Union would lead to a quarter of a million square feet of photographs. If these were assembled into a single photograph of the Soviet Union, it would cover more than five football fields and require a microscope for detailed analysis. Some means of directing the search is needed.[23] Potentially useful kinds of such *prior information* include: terrain characteristics, target-associated infrastructure, results of previous searches, knowledge of the inspected side's operational habits, and other intelligence data.

Terrain

In most areas, terrain sharply limits the possibilities for the locations of many kinds of TLIs. Land-mobile SS-20 or SS-25 missile launchers, for example, might not be able to enter swampy land. More generally, land-mobile missile launchers are likely to be found in regions where accessible terrain is not only available but plentiful, because the concept of operation of such launchers calls for them to be able to disperse and create enough uncertainty as to their whereabouts to stymie an attack by ballistic missiles. This consideration would lessen the area of the region in which launchers might be found. However, as mentioned earlier, such launchers might use roads to enter and move about in a region of difficult terrain.

Infrastructure

Infrastructure can provide many valuable clues to the location of reconnaissance targets. A photointerpreter's account of how she found the German V-1 cruise missile during the Second World War shows her use of infrastructure clues. (See app. A.) More recently, a British analyst of Soviet earth-resources satellite *Soyuz Karta* stereoscopic pictures discerned a 750-meter-long building, new roads, embankments, and signs of possible excavation at a site in Iraq; these clues (taken together with information collected by Kurdish separatists in the region) led the analyst—a minerologist by training—to conclude that the Iraqis were developing the site as a "uranium mine" or a nuclear weapon production plant.[24]

In general, the tracks made by troops and vehicles "are the most important and obvious signature of any military activity."[25] Not only do some military vehicles create tracks unlike any civilian vehicle, but the presence of such military-related infrastructure can be given away by tracks: the presence of barbed

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[23] In the case of a much smaller country, some 25 linear miles of film were shot by U-2s and low-flying aircraft in the course of the Cuban Missile Crisis. (Robert Kennedy, *Thirteen Days* (New York, NY: W.W. Norton, 1971), p. 46.)

[24] "Satellite Reveals 'Uranium Mine'," *Jane's Defence Weekly*, Nov. 3 1990, p. 879.

[25] *Imagery Analyst*, Soldier's Manual STP 34-96D1-SM (Washington, DC: Headquarters, Department of the Army, November 1987), p. 2-456.

Box 6-I—The GENETRIX Project

The GENETRIX project presents, in purest possible form, an airborne search undertaken without any recourse to existing knowledge of important targets' locations.

During the mid-1950s, the U.S. Strategic Air Command launched a program of balloon-borne reconnaissance of the Soviet Union and the People's Republic of China. High-altitude balloons bearing automatic cameras would float East from Europe across the Soviet Union and the P.R.C. to Arctic recovery areas in the Pacific. In January and February of 1956, 516 balloons were launched, of which fewer than 10 percent were recovered. These furnished almost 14,000 100-square mile exposures of Soviet or Chinese territory, accounting for about 8 percent of those countries' area. The utility of the pictures was characterized as suitable only for "pioneer" work, and the Soviet reaction—which included a press conference featuring many fallen balloons—was vehement.[1]

"Pioneer reconnaissance" was elsewhere defined at that time as a resolution of 20 to 400 feet; pictures taken at such resolutions would not be useful to military photointerpreters.[2] The balloons may have performed at the better end of this range. They carried pairs of cameras whose fields of view slightly overlapped—with a then-readily-attainable film resolution of 10 lines per millimeter[3] and optics to match, the resulting 9- × 9-inch images[4] would, if showing a region 10 statute miles on a side, attain a ground resolution of

$$(5{,}280 \times 10) \div (9 \times 25.4 \times 10) = 23 \text{ feet.}$$

From a mapping standpoint, however, the pictures were quite usable, and the program was characterized as a successful and even cost-effective mapping mission.[5]

The militarily disappointing results of the GENETRIX program are instructive because they stem in large measure from the scattershot nature of the search. Not only were the users unable to target the balloons (some even missed the Soviet Union altogether), but their first order of business upon receipt of the product was to determine where the balloons had been. The principal lesson of the project is the price it paid for its inability to capitalize upon existing information as to the whereabouts of interesting targets.

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[1] This account from Thomas Crouch, *The Eagle Aloft* (Washington, DC: Smithsonian Institution Press, 1983), pp. 644-647.

[2] Merton E. Davies and William R. Harris, *RAND's Role in the Evolution of Balloon and Satellite Observation Systems and Related U.S. Space Technology* (Santa Monica, CA: The RAND Corp., 1988), pp. 26-27. French SPOT and U.S. Landsat pictures fall in the "pioneer reconnaissance" category according to this standard.

[3] Ibid., p. 11.

[4] Ibid., p. 60.

[5] Ibid., p. 61: At just under $50/square mile, GENETRIX collected mapping data on the Soviet Union more cheaply than any other means then in use for mapping the United States.

wire (a difficult photographic target), for example, can be deduced by observing the otherwise inexplicable convergence of tracks.[26]

Soviet SS-20 and SS-25 mobile missiles deploy to prepared sites consisting of turnouts and berms.[27] To assure survivability, the Soviets have doubtless prepared far more of these sites than there are missiles, but the sites, and the regions surrounding them, are still likely places to look for mobile missile launchers.

Between deployments, SS-25s (and SS-20s, to be eliminated under the provisions of the INF Treaty) occupy unique sliding-roof buildings. Clandestinely deployed missiles would probably not be based in buildings of the same appearance as those housing the overtly deployed force, but the sliding- roof feature (which enables the missile to be launched without moving the TEL outdoors) might be retained.

Despite their off-road capability, SS-20 and SS-25 missiles are more mobile on roads than off, and therefore an aerial monitoring search for these missiles or their shelters could be guided by the road network. Bridges would channelize missile launcher traffic (along with all other traffic), making them and their vicinities especially likely places to find TELs.

Rail-mobile SS-24 missiles are constrained by an even more obvious item of infrastructure: railroad tracks. Railroad tracks seem to be important for Soviet silo-based ICBMs as well: the existing fields string out along the Trans-Siberian Railway. As is well-known, most of the Soviet Union's rail network is broad-gauge (5 feet): the SS-24 operates on this broad-gauge track.[28] Some western regions of the Soviet rail network have the same standard-gauge (4 foot, 8.5 inches) track as the neighboring European countries. The standard-gauge sectors would merit some surveillance, lest the Soviets exploit U.S. overreliance on this particular infrastructure cue and clandestinely produce illegitimate SS-24s deployed in standard-gauge railcars.

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[26] *Ibid.*, p. 2-457.

[27] As shown in *Soviet Military Power*, various issues.

In general, railroads are such an important part of the Soviet infrastructure that an aerial search for almost any kind of facility could sensibly be begun on the assumption that the facility would have handy access to a railroad.

Illicit TLIs, especially small numbers of them, might well be found mixed in with legitimate TLIs or even non-TLIs. For example, SS-23s (TLIs banned by INF) were found amidst the treaty-unconstrained missiles of an East German Scud-B unit.[29] As mentioned in chapter 6, an aerial monitoring aircraft searching railroad tracks for SS-24 trains would also see many ordinary trains, probably seeing one in motion every 50 miles or so and many others stopped at sidings or in railyards. These trains would have to be judged missile-free. Discrimination of missile-carrying trains from ordinary ones might not be easy: the United States plans to disguise its Peacekeeper-carrying trains as ordinary ones,[30] so the Soviets could do the same without incurring charges of the use of ''deliberate concealment measures'' to defeat NTM.

Certain treaty provisions could have the effect of mandating infrastructure. ''Designated deployment areas,'' regions expressly designed to simplify detection without so constraining weapon deployment as to constitute a threat to survivability, have been proposed for mobile ICBMs under START. Conversely, designated test areas are designed to assure the verifier that weapons found within their limits are not deployed, but are merely test items. The SALT I ABM Treaty codifies infrastructure in this way. Finally, the intended purpose of a deployment may be established by its location: the ABM Treaty requirement that putative early warning radars face outwards from positions on the perimeter of their countries establishes that they are not proscribed battle management radars.[31] Not only do such mandated details of infrastructure facilitate the counting of deployed weapons; they also simplify the decisionmaking process in case a TLI is sighted outside an allowed region: ''detection of a single item in proscribed places or times would constitute a violation.''[32]

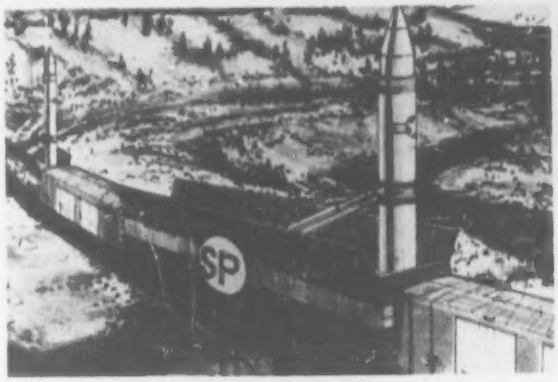

Photo credit: U.S. Department of Defense

Plans for possible rail-mobile deployment of the U.S. Peacekeeper ICBM call for the use of normally marked trains.

Finally, and most simply, TLIs are likely to be found near other TLIs, and other military hardware. Even targets such as mobile missile launchers, which try to spread themselves out for survivability's sake, spread out only on a tactical level and not on an national one. If total bans on weapon systems, like total bans on operating certain weapon systems outside of designated deployment areas, are especially verifiable because ''if we see even one then we'll know they're cheating,'' then having seen more than one would help clinch the case. Thus searchers who find a target might do well to modify their search plan and look for more targets in the same region.

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[28] *Soviet Military Power 1990*, op. cit., footnote 12, pp. 51-52.

[29] *Washington Times*, May 4, 1990, p. 6.

[30] Applying commercial emblems, authentic-looking amounts of dirt and rust, and even blending in a few real freight cars. Remaining functionally related observable differences include the number of axles on the missile-carrying cars and the undercarriage of the fuel car. (''U.S. Plays Cloak-and-Boxcar,'' *Chicago Tribune*, June 14, 1989, p. 1.)

[31] The famed Krasnoyarsk radar violates this condition.

[32] Ivan Oelrich, ''The Verification of Conventional Arms Limits,'' in *New Technologies for Security and Arms Control*, Eric H. Arnett, ed. (Washington, DC: American Association for the Advancement of Science, 1989), p. 192.

Previous Searches

In a search for a stationary target, e.g., a clandestine factory, the results of all searches can be considered simultaneously, amounting to one big search. In dealing with mobile targets, e.g., mobile missile launchers, one must keep in mind the possibility that a target has moved to the site of an earlier picture, so that it can evade detection even after the entire region has been photographed.

Studies addressing the search for mobile, or "relocatable,"[33] surveillance targets, e.g., mobile missile launchers, often contain assumptions about such targets' movement habits based upon current practice. Because these habits may be as much a matter of policy as of necessity, they could perhaps be changed—say, by making movement more frequent—if necessary to elude detection by a newly deployed surveillance asset or a newly introduced program of aerial monitoring. (See also box 6-J.)

Other Sources of Prior Information

Other sources of prior information include analysts' assessment of what developments to expect, previous sightings of the same item, and the fruits of other intelligence collection means.

Unaided by previous sightings or collection by other means, an intelligence collection effort can be aided by an awareness of the operations of one's own side's forces. For example, the British discovery of a German V-2 intermediate-range ballistic missile at Blizna (see app. B for an account of this) may have been aided by the analyst's having seen a V-2 before, in a picture of Peenemünde. Similarly, the initial Allied discovery (also described in app. B) of the German V-1 ground-launched cruise missile was owed partially to the photointerpreter's having been briefed on the possibility of pilotless aircraft and the ramps needed to launch them: these cues were the result of other means of intelligence collection.

Box 6-J—Mobile Targets

In looking for a fixed facility such as a factory, one can at least count on the fact that that the target will not move between searches. Searches for *mobile* targets, such as Soviet SS-25 ICBMs, are complicated by the fact that the target might move during the search. In an aerial monitoring search, in which the target country is examined in installments, even cumbersome "relocatable" targets might move between installments of the search. The contrast between searching for mobile targets and immobile ones bears some resemblance to the contrast between sampling with replacement and sampling without replacement in, for example, a reentry vehicle on-site inspection (RVOSI) context.

In calculating the probability of finding a target (assuming some known target density), the case of mobile targets can be handled by the confetti-search formalism described above. In what might be called "the (mathematically) ideal worst case," in which the targets are constantly moving about and the fact that a target has not been seen at a particular place has absolutely no bearing on whether or not there might be a target there the next instant, the expected number of targets found is

$$\text{total} \times (1 - e^{-\text{effort/area}}),$$

(see box 6-G) instead of

$$\text{total} \times (\text{effort/area})$$

The probability of finding at least one target is still

$$1 - e^{-\text{total} \times \text{effort/area}}$$

as in the case of randomly located stationary targets.

Radio direction-finding can contribute strongly to the a priori information available to searchers. Most observers believe that an aerial monitoring agreement will not include collection of electronic intelligence by the flights themselves, but the planners of the flights could capitalize on electronic intelligence obtained by other sources.

Other sources of intelligence could also be of great use to planners of aerial monitoring searches. The search effectiveness of U-boat skippers prowling the Atlantic during the Second World War, for example, was doubled when they had access to radio intercepts revealing the intended routes of Allied convoys.[34]

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[33] The term connotes something less than full mobility; usually the inability to operate on the move, and perhaps even the need to spend setup time between cessation of movement and onset of operations, and teardown time between cessation of operations and onset of movement.

[34] Operations Evaluation Group Report No. 533, available from the Center for Naval Analyses, Alexandria, VA.

The Problem of Misleading Prior Information

Prior information, or simply predisposition, can reduce the probability of detection as well as raise it. R.V. Jones recounts that the ''ski'' or ''catapult'' V-1 launchers at Peenemünde (on one of which Flight Officer Constance Babington-Smith was later to discover the V-1 itself):

> were, for example, interpreted as ''sludge pumps,'' a theory perhaps coloured by the interpreter's previous experience as an engineer with a river Catchment Board after his Cambridge Ph.D. thesis on classical hydraulic engineering[.][35]

Jones does not mention that a long-term land-reclamation project going on at Peenemünde was another source of confounding false clues as to the true nature of the launchers. (See also app. A.)

In the case of the V-2, search for launching sites in France was originally planned on the basis of an assumption that launchers would be sited close to rail lines.[36] Only later was a V-2 recognized in a photograph of Peenemünde on what would today be called a TEL, disassociated from any rail line, leading to the realization that the search for rocket launchers near rail lines—and indeed the search for fixed rocket launchers at all—was fundamentally misconceived.

Prior Information and the Assumption of Rationality

Most of what we have called ''prior information'' regarding the placement of rocket launchers and so on contains, to greater or lesser degree, reasoning as well as facts. Much of this reasoning concerns what the other side would or would not do, typically based on an assumption that they are reasonable people. For example, advocates of the INF Treaty—while admitting that illicit SS-20s would be very difficult to detect—discounted fears that the Soviets would hide illicit SS-20s in SS-25 canisters on the grounds that doing so would simultaneously deprive the Soviets of the military benefits of having a missile that could reach the United States and the political benefits of having a missile demonstrably targeted at Europe:

> If they wanted to cheat on the INF Treaty, I would give them a little more credit than taking an SS-20 and putting it in an SS-25 canister . . . . The problem is, you would have to ask why they would do it. The purpose of the SS-20, in my opinion, was to provide a political threat to Europe. An SS-20 which is covert, hidden, or an SS-20 which is in an SS-25 canister would not represent that political threat.[37]

Some may question any such argument based on perceived lack of Soviet incentives or lack thereof. It is true that such reasoning can sometimes lead the analyst astray, but the error so induced is rarely larger than the penalty paid by the other side for its failure to act rationally.

For example, the British detection of the V-2 was considerably retarded by the belief that a militarily effective ballistic missile of sufficient range was either impossible to build or ludicrously uneconomical. In particular, once the V-1 program was understood, those who believed in the existence of a V-2 program had to weather the argument that the Germans would not go to the trouble of building a ballistic missile simply to deliver the same size warhead as was carried by their V-1 cruise missile. As it turned out, the V-2 missile did in fact deliver a warhead only slightly larger than that of the V-1, and with much greater trouble and expense. Those in Britain who doubted the existence of the V-2 program on the grounds that Germany would have no incentive to build two weapons for one mission neglected the considerations of improved penetration, interservice equity,[38] and technological romanticism[39] that compelled the German authorities to allow the Wehrmacht and Luftwaffe each to develop its own system.[40]

Though the British were *surprised* by the V-2 project, they were not *dismayed*: they were correct in their belief that the weapon would be a grossly inefficient use of German resources and erred only in believing that the Germans would abandon the project accordingly. The German war effort needlessly bore the burden of ballistic missile production, with each V-2 representing a debit to the Germans of many V-1s' worth of resources and thus a saving to the British of many V-1s' worth of damage. Analogously, advocates of the idea that the Soviets would not place SS-20s in SS-25 canisters might well (and in some cases do) take the attitude that "if the Soviets did that, they are sort of playing into our hands."[41]

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[35] R.V. Jones, *Most Secret War* (London, England: Hamish Hamilton, 1979), p. 433.

[36] Constance Babington-Smith, *Air Spy* (New York, NY: Harper and Brothers, 1957), p. 215.

[37] Testimony of Major General William F. Burns, *The INF Treaty*, hearings before the Committee on Foreign Relations, U.S. Senate, Part 5, 100th Cong., 2d. sess., p. 89.

[38] Though this motivation was anticipated by some in Britain. (Jones, op. cit., footnote 35, pp. 456-457.)

[39] Ibid., pp. 573-575; and Michael J. Neufeld, ''Weimar Culture and Futuristic Technology: The Rocketry and Spaceflight Fad in Germany, 1923-1933,'' *Technology and Culture*, vol. 31, No. 4, October 1990, especially the concluding paragraph.

[40] See also David Irving, *The Mare's Nest* (London, England: William Kimber & Co. Ltd., 1964).

The assumption of rationality is simply an instance of the usual worst-case planning: the worst case is that the other side behaves rationally and in one's own worst interest. This standard is sometimes equated to the more dangerous "mirror-imaging" assumption that the other side behaves rationally and in what we see as its own best interest, which may not be the same thing.[42] For example, U.S. analysts' consistent underprediction of the growth of the Soviet ICBM force in the 1960s has been ascribed to mirror-imaged imputations of the costs and benefits to the Soviets of building ICBMs.[43] Interestingly, it has been pointed out that mirror-imaging would have correctly predicted the growth of the Soviet ICBM force if the U.S. civilian analysts had imputed to Soviet military planners the mindset of their uniformed U.S. counterparts, not that of U.S. civilian analysts.[44]

One could undertake a program of aerial monitoring without any recourse whatsoever to assumptions about the other side's rationality. Searches in such a program would be scoped only by the physical constraints under which the other side operated: aircraft would not search for ships in the middle of deserts or for missile silos in quicksand. However, the need to search for silos in the desert and ships in the quicksand would deprive the searching side of any means by which to cut down on the raw area it needed to search. A better aerial monitoring program would impute rationality to the other side, but also hew to the assumption that the other side was—rationally—pursuing the most damaging possible course of action.

Searches in such a program would respect physical constraints and, to some degree, fiscal ones as well; searches for isotope separation plants, for example, would be concentrated in regions plentifully supplied with hydroelectric power plants. The "if they want to, let them" principle would be observed: occasional searches of inappropriate or unlikely terrain would be performed, but the principal search effort would be allocated to the regions most likely to contain the objects of the search. The theoretical ideal would be to create a situation in which the costs of committing a violation—including the difficult-to-quantify cost of being caught—were equalized over all locations in the other side's territory.[45] Any other allocation of search effort would create favorable locations for cheating and thus allow it at too low a cost.

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[41] Testimony of Major General William F. Burns, op. cit., footnote 37, p. 90.

[42] The special case of deterrence deserves mention because of its importance in U.S. planning. To be deterred may be in the adversary's best interest, but for him or her to fail to be deterred is in one's own worst interest. As in the case of Pearl Harbor, the would-be deterrers' eventual victory does not assuage the dismay they feel when the target of their deterrence fails to see the light and executes a worst-case attack.

[43] Walter Laqueur, *A World of Secrets: The Uses and Limits of Intelligence* (New York, NY: Basic Books, 1985), pp. 190-194.

[44] Bruce D. Berkowitz and Allan E. Goodman, *Strategic Intelligence for American National Security* (Princeton, NJ: Princeton University Press, 1989), pp. 91-93. Such insights can be exploited on the tactical level as well. During the Cuban Missile Crisis, when aerial photography revealed that "the Russians and Cubans had inexplicably lined up their aircraft wing tip to wing tip on Cuban airfields, making them perfect targets, [President John F. Kennedy] requested General [Maxwell] Taylor to have a U-2 fly a photographic mission over our fields in Florida. 'It would be interesting if we have done the same thing,' he remarked. We had. He examined the pictures the next day and ordered the Air Force to disperse our planes." (Robert Kennedy, op. cit., footnote 23, pp. 37-38.)

[45] Similarly, the air search effort for U-boats in the Second World War was apportioned over night and day so as to make surfacing equally hazardous at all times. See Brian McCue, *U-Boats in the Bay of Biscay* (Washington, DC: National Defense University Press and the U.S. Government Printing Office, 1990).

APPENDIXES

Appendix A

MONITORING NONZERO LIMITS

In chapter 6, our discussion addressed the monitoring of limits on banned systems, e.g., the SS-20.[1] In verifying compliance with a ban, one can follow the line of reasoning made familiar in discussions of the Intermediate Range Nuclear Forces (INF) Treaty, that "the detection of a single SS-20, and not even the missile, just the launcher or a single-bay garage that was supposed to have been eliminated by the treaty, would be a violation of the treaty."[2] Other treaty limitations allow certain systems, but restrict their numbers. Such nonzero limits are much harder to monitor through aerial surveillance than are the total bans addressed so far in this report. Not only is the "If we see even one, then it's a violation" dictum inapplicable, but even the more sophisticated notion of extrapolation from a sample is likely to fail.

Reporting of the results of public opinion polls has accustomed Americans to the power of extrapolation from polling of a manageably small sample to deductions about large populations. Some pollsters state their sample size and provide an estimate of the accuracy of the result: a common protocol polls about 1,600 Americans and returns what is described as a "3-percent margin of error" and a "95-percent confidence level." The Gallup organization, for example, describes these parameters as reflecting a 19-to-1 chance that the response of the entire American population, if taken, would not have differed from the response of the 1,600 Americans by more than three parts in one hundred.[3] One may reasonably wonder whether aerial monitoring could hold out the hope of providing similarly accurate data on treaty-limited (but not banned) items on the basis of the modest sample size available from a single flight. In general, the answer is that it cannot.

Such an extrapolation scheme would use an aerial monitoring flight to examine part of the region in which Treaty-Limited Items (TLIs) were deployed.[4] TLIs in this region would be counted during the flight and then a "population estimate" for the whole region would be made on the basis of proportionality: if 10 percent of the deployment region had been inspected, the enumerated TLIs would be construed as 10 percent of the total, leading to an estimate for the total. The flaw of this scheme is that it assumes an even distribution of TLIs,[5] whereas there is no reason to think that such an assumption would be true, and several reasons to think that it would be false. Communications and logistical arrangements, for example, might well be eased by the operation of mobile missiles in groups. More subtly, the missiles' effectiveness as a deterrent[6] would be enhanced by bunching them up and thus linking their fates: the planner of a barrage or reconnaissance-strike attack would then have to contend with the possibility that all of the targets would survive.[7] Thus bunching has to be considered likely, weakening the aerial observer's ability to estimate the total number of deployed TLIs based upon the number observed in some part of the deployment region. Finally, the other side might take deliberate steps to make sure that the sample population was—in one or more respects—simply not representative of the whole. A clever treaty violator could slant the results of inspections, allowing enough TLIs to be seen that the inspecting side would conclude that a plausibly large, but treaty-compliant, force had been fielded when in fact the true force was far larger than allowed by the treaty. In public-opinion polling, there is no "other side" to take such steps.[8]

In a similar vein, some have suggested that treaty verifiers borrow the statistical methods used by industrial "quality assurance" specialists. These methods also offer little hope in the case of monitoring treaty compliance, because they address the question of how to feed back information gained from product inspections into the manufacturing process, so as to reduce the number of defects produced. These methods are inapplicable in arms control treaty monitoring, because one side does the

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[1] The SS-20 is banned under INF.

[2] The point was made in this instance by Major General William F. Burns, *The INF Treaty*, hearings before the Senate Committee on Foreign Relations, U.S. Senate, 100th Cong., 2d sess., Part 5, p. 88.

[3] Gallup on-line service. This description would strike a classical statistician as lacking in mathematical rigor because it comes close to assigning a probability to something which is in fact either true or false: the proposition that the response of the population as a whole is within 3 percent of that of the sample.

[4] Some treaty arrangements would facilitate such monitoring by creating prescribed deployment regions for, say, land-mobile intercontinental ballistic missiles (ICBMs).

[5] As the pollsters caution us, sampling error is only one source of error in the final estimate.

[6] A logical mission for a mobile ICBM, with its heavy investment in survivability.

[7] This possibility—resulting from the case in which he happens to overlook the one subregion that contained the entire force—would loom larger in the attacker's mind than the contrary case, in which all of the targets are found and destroyed.

[8] Though some pollsters have explained the discrepancy between their results and those on Election Day by an alleged reluctance on the part of voters to admit that they intend to vote for especially controversial candidates.

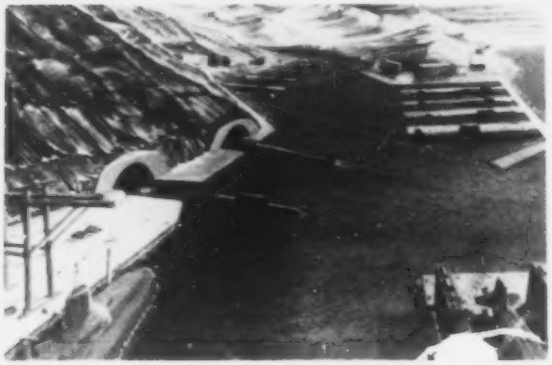

Photo credit: Artist's concept of Soviet s[illegible]ine port, U.S. Department of Defense

Ballistic missile-launching submarines are restricted, but not forbidden, by arms control treaties. Counting them represents a typical task in the monitoring of nonzero limits: one must gain assurance that no more than the allowed number exist even though not all can be seen at once.

monitoring and the other side does the compliance (or violation).[9]

Tags

The use of *tags* (nontransferrable, nonduplicable identifying markers—analogous to automobile parking stickers—issued by the inspecting side to the owning side) has been proposed to facilitate monitoring. Tags might be made readable from aerial monitoring aircraft.[10] A tagging scheme would avoid difficulties posed by potential bunching of TLIs because it would not rely on statistical sampling: enough tags are handed out to account for the allowed number of TLIs, and any TLI found without a tag is presumed to be a violation of the treaty.

Even in the absence of a detected violation, however, statistical analysis of the tags found on the legitimate TLIs could enhance the tags' utility as a verification device. One such procedure,[11] conceptually similar to the capture-release-capture protocol used to estimate bird populations, would consider two successive "takes" of tag numbers as samples of the larger population. Those TLIs seen in the first "take" are considered to be "banded." Assuming that the chance of a TLI being seen in the second "take" is not increased or decreased by the inclusion of the TLI in the first "take," the proportion of "banded" TLIs in the second "take" ought to be equal to their proportion of the population as a whole. For example, if the first "take" identified 30 TLIs, 2 of which appeared in a second "take" of 20 TLIs, one would conclude that the 30 TLIs represented 10 percent of the total population, yielding an estimate of 300 for the total. If this total is *less* than the allowed total, then (assuming that the other side has not voluntarily sacrificed some TLIs) the estimated "total population" is not the true total population but only the total subpopulation of which these observations have been made. In this case, the aerial monitoring needs to be expanded because its scope does not even cover all the legitimate TLIs. A total *greater* than the allowed total would indicate that, for some reason, TLIs seen in the first take were less likely than others to be seen in the second "take"; this finding would suggest that TLIs are being rotated through the region subjected to aerial monitoring, an ominous prospect.

With the possible exception of flights examining TLIs restricted to designated deployment areas, a single aerial monitoring flight is unlikely to see enough TLIs for the "banding" approach to be used. A generalization of the above method, however, could deal with the very small takes—perhaps of only one TLI even on a "good day"—expected under some aerial monitoring regimes. Under this generalization, each sighting of a TLI would be logged and periodically—perhaps annually—the sightings would be totaled so as to create a listing of those TLIs seen once, those seen twice, those seen three times, and so on.

One would hardly expect sightings to be absolutely evenly distributed among TLIs. Through chance alone, some will be seen more than others. The *Poisson distribution* tells us how much "clumpiness" to expect in the repeat sightings. Fitting the observations to a Poisson distribution would reveal any departure from the expectation that the tendency of a TLI to be sighted is unrelated to its previous history of sightings. If the data failed to conform to a Poisson distribution because of an unduly small proportion of repeat sightings, one would have reason to suspect "hot-bunking,"[12] or some other form of rotating TLIs through the region subjected to aerial monitoring. If, on the other hand, the data departed from a Poisson distribution by virtue of an overly large propensity of TLIs to be sighted repeatedly, then one would suspect that the inspection process was somehow being manipulated so that the same TLIs, once seen, were presented over and over.

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[9] As a saying now favored by quality assurance specialists holds, "Quality cannot be 'inspected in.' " The import of this saying is that inspection can only hope to filter out rejects, and cannot be used as a means of actually adding quality. Quality can only be added by manufacturers, not inspectors. Similarly, treaty compliance cannot be 'inspected in.' Moreover, the producers and the inspectors are, in the case of treaty compliance, on different sides. Such a contrast between acceptance testing and treaty monitoring was drawn by Patricia M. Lewis in "Verification of Conventional Forces in Europe," *IEEE Technology and Society Magazine*, December 1990/January 1991, p. 11.

[10] Tags are briefly discussed in OTA's unclassified *Verification Technologies: Measures for Monitoring Compliance With the START Treaty—Summary*, OTA-ISC-479 (Washington, DC: U.S. Government Printing Office, December 1990).

[11] Proposed by Stephen Davis in "Verification and Compliance for Arms Control," *Comparative Strategy*, vol. 9, No. 4, 1990; pp. 403-413.

[12] In this method of cheating, an operating base supports excess TLIs by keeping some in the field at all times.

If the numbers of TLIs seen five, four, three, two, and one times each seem consistent with a Poisson distribution, one would be justified in extrapolating to a number seen zero times, and thus to an estimate of the total population size. The Poisson-based approach is particularly attractive because of this self-checking feature, by which the applicability of the imputed Poisson distribution can be checked in the cases of repeated sightings before it is used to estimate the number of TLIs never sighted.

Additionally, the Poisson system does not rely on any knowledge of how many tags have been given out.[13] For this reason, as well as the self-checking feature, it is promising as a means of interpreting sightings of "buddy tags." Buddy tags, analogous to automobile license plates, uniquely identify the TLIs with which they are associated, yet (in some schemes) forego the elaborate precautions against duplication and transfer that complicate many conventional tagging schemes. Unlike these more technologically ambitious tags, buddy tags could easily be made large enough that they could be read from an airplane.

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[13] For this reason, it would be well suited to use in conjunction with *intrinsic tags* (innate identifying characteristics of individual TLIs—analogous to fingerprints--catalogued by the inspecting side). These hold out the promise of great security from illicit transfer or duplication. However, most proposed intrinsic tags, e.g. the marks left on the TLI by the tools used to make it, require such close examination of the TLI as to preclude the serial reading of the tags.

Appendix B
PHOTOINTERPRETATION AND IMAGE PROCESSING

Summary

Collection of images is only the beginning of aerial surveillance. They must be processed and interpreted to make the information they contain available as a basis for action or decision. Camouflage, concealment, and deception methods can be effective, but do not always defeat the photointerpretation and image processing steps. Image processing, the enchancement of pictures through filtering, pattern recognition, and contrast enhancement, seems amenable to various forms of automation. Automation can also assist in photointerpretation, but true automation of photointerpretation may lie far in the future.

Introduction

Interpretation of aerial photography requires that skilled analysts devote considerable time to each picture, using optical equipment of various kinds and a comprehensive knowledge of sought-for targets and their tell-tale traces, or "signatures." Photointerpretation is the art of eliciting information from photographs. Image processing, now largely done by computers, is the refinement of pictures so as to make them more amenable to photointerpretation. Photointerpretation and image processing each benefit from the repeated collection of imagery over time.

Photo credit: Department of Defense

Despite some degree of automation, the photointerpreter's task remains largely one of skill, patience, and memory.

Detailed analysis and reporting might well consume a person-hour per picture, or roughly a person-week of work to exploit fully the data taken in a single aerial monitoring sortie. Estimation of the time needed to process aerial photography is in some sense impossible because a photointerpreter's work is never done.[1] There is always some chance that extra time spent can result in extra information gleaned, perhaps crucial information not discerned initially: some photographs will have been set aside as unpromising, and even promising ones may not receive full exploitation. For example, British photography of the German missile test facility at Blizna (Poland) captured a V-2 intermediate-range ballistic missile; but the missile's image passed unnoticed through the entire image interpretation process, only to be discovered months later by a government scientist untrained in image interpretation but willing to go over the photographs "millimeter by millimeter for many minutes."[2]

Examples of Photointerpretation

During the Second World War, British photointerpreters examined imagery of the German test site at Peenemünde for signs of new rocket and jet weapons under development there. Constance Babington-Smith's account of how she found the V-1 ground-launched cruise missile merits quotation at length not only for the insights it gives into the photointerpreter's use of all the information at her disposal, but for the attitude with which she approached her task.

> I decided to follow the dead-straight road which led northward along the eastern boundary of the airfield toward the Baltic shore. I passed the limits of the airfield and went on toward the extreme edge of the island. To the right lay an untouched stretch of marshy foreland, but on the left there was a great deal going on—the long-term project of land reclamation for extending the airfield . . . . Right at the edge of the road there was something I did not understand—unlike anything I had seen before . . . . Rumors of "launching rails" for secret weapons had reached me earlier; and ever since I had been briefed about pilotless aircraft I had been on the lookout for a catapult of

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[1] Theoretical reasons, as well as experimental results, suggest that the cumulative probability of finding a target in a visual search, e.g of a photograph, depends upon the time devoted according to the function

$$p = 1 - e^{-kt},$$

where the constant k embodies the difficulty posed by the search because of the size of the target, the size of the search area, the contrast between the target and the background, and so on. The asymptotic approach of p to unity suggests that the interpreter's work is never done. See also Koopman, *Search and Screening* (Pergamon, 1980) especially app. E.

[2] R. V. Jones, *Most Secret War* (London: Hamish Hamilton, 1978), p. 550. Jones had earlier been the first to find a V-2 image anywhere, in a picture of the test facility at Peenemünde (Germany) which had also undergone previous interpretation to no avail. (Jones, pp. 433-434.)

Photo credit: National Air and Space Museum, Smithsonian Institution

British reconnaissance photo of Peenemunde, site of German World War II rocketry research. The arrow indicates a V-2 missile lying on its side. Professor R.V. Jones discovered the V-2 missile in a photograph such as this.

> some kind. I pondered over the photographs and reviewed what I had found. There were four of these strange structures. Three of them looked very much like the sort of crane that have a box for the operator and a long movable arm. But the fourth seemed different, and it was the one that drew my attention most. It was evidently a sort of ramp banked up with earth—you could tell that from the shadow—supporting a rail that inclined upward towards the water's edge. "I'd better check with the Industry interpreters," was my first thought. "They probably know all about these things already. So I took the prints along to the Industry Section, and was told that these "things had been looked at long ago, and interpreted as something to do with the dredging equipment. Back at my desk, I gazed at the photographs again . . . . [On this basis, Flight Officer Babington-Smith asked to see a newer set of Peenemünde photographs.] Only the first print of the run showed it, so there was no stereo pair. The quality of the photographs was poor, but even with the naked eye I could see that on the ramp was something that had not been there before. A tiny cruciform shape, set exactly on the lower end of the inclined rails—a midget aircraft actually in position for launching.[3]

The following extract from R.V. Jones's *Most Secret War* recounts Dr. Jones's 1944 discovery of German V-2 intermediate-range ballistic missiles at a test facility in Poland. These missiles, not yet used in action, had previously been seen only at the Peenemünde test site in Germany. The account illustrates several features of aerial search for such weapons:

1. the importance of cuing by other intelligence sources, in this case signals intelligence;
2. the way infrastructure points to weapon presence;
3. the way preconceptions based on the way one's own side operates, or would operate, color one's interpretation of photographic evidence; and
4. the enhanced recognition ability conferred by previous sightings of the same target.

Jones wrote:

> Something very odd had been taking place in Poland because Blizna[4] was from time to time dispatching what were called *Geräte* (apparatuses) back to Peenemünde. What could these be? I could understand things being sent from Peenemünde to Blizna for trial, but what would be worth sending back? I began to wonder whether these might be items such as rocket jets that had been tested, but there was no clue in the Ultra messages[5] regarding their nature. Certainly there were plenty of them, to judge by the numbers by which they were identified. The first number that I had was 17,053, about which I had learnt on 17 June, and by early July the highest number I had heard of was 17,667. How could I prove that these were rocket components? If only we had complete photographic cover of the Blizna area we could have found the launching site or the test rig, and perhaps found a rocket there; but even though I had requested further cover more than a month before, fresh photographs had not yet been obtained.
>
> As I pondered, I tried to put myself in the position of the Germans working in unfriendly territory, and began to wonder whether—even with the rivalry between the German Army and the Luftwaffe—I would have used two sites, each of which would have to be defended, when there should be enough room at a single site to launch both flying bombs and rockets. I therefore took out again the 5th May photographs of the flying bomb compound, even though I knew these had been exhaustively searched at Medmenham. Going over them millimetre by millimetre for many minutes, I suddenly realized that a familiar outline had "clicked" into place with the memory of one that I had seen before—on the photograph of Peenemünde on which I had first found the rocket . . . .
>
> But the account was not yet complete, because there was no sign of any launching apparatus. Our experts had assumed that the rocket would need to be fired from some sort of a gun at a speed of 100 metres per second to make it stable in its initial flight, and there was a large tower erection at Peenemünde which had been assumed to be for this purpose; but there was no such tower at Blizna. So on a subsequent evening I scanned the photographs again, looking for a concrete platform; ultimately in the center of the compound, and showing only faintly because that part

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[3] Constance Babington-Smith. *Air Spy* (New York, NY: Harper and Brothers, 1957), pp. 226-229.

[4] Known to Jones as a test site for the V-1.

[5] These were encrypted German radio signals intercepted by the British and decrypted. "Ultra" denoted the close hold the British kept on the results of this effort; "Enigma" was the name of the encryption machine used by the Germans.

> of the photograph was so light, was a square of about 35 feet wide. With this evidence and that from Molay,[6] could it be that the rocket needed no launching equipment more elaborate than a flat pad, and simply stood vertical, nose uppermost? If so this would explain the 40 foot "columns" we had sometimes seen standing at Peenemünde. The rocket would take off by itself, stabilized by gyroscopes and the deflectable "jet rudders" we had found among the components mentioned in the Enigma messages.[7]

Babington-Smith, an expert, and Jones, by all accounts a most remarkable individual, make their work sound easy. In fact, considerable training is required. During the Cuban Missile Crisis, policymakers had found themselves relying on the testimony of experts despite having the photographic evidence directly at hand of Russian missiles being deployed in Cuba.

> Photographs were shown to us. Experts arrived with their charts and their pointers and told us that if we looked carefully, we could see there was a missile base being constructed in a field near San Cristobal, Cuba. I, for one, had to take their word for it. I examined the pictures carefully, and what I saw appeared to be no more than the clearing of a field for a fair or the basement of a house. I was relieved to hear later that this was the same reaction of virtually everyone at the meeting, including President Kennedy. Even a few days later, when more work had taken place on the site, he remarked that it looked like a football field.[8]

Change Analysis

Perhaps the most potent tool in the photointerpreter's hands is *change analysis*, the study of a target through interpretation of its evolving appearance. When she got the picture containing the V-1, Babington-Smith's attention was drawn to the new missile because of its appearance on a ramp that had been empty in the earlier picture. Babington-Smith later cited the German failure to "use comparative covers" (i.e., to perform change analysis), along with their lack of stereoscopic imagery, as the reasons that the German photointepretation effort "never even got to first base" despite impressive basic optics.[9]

As will be discussed below, some mechanical aids are available to help the photointerpreter perform change analysis.

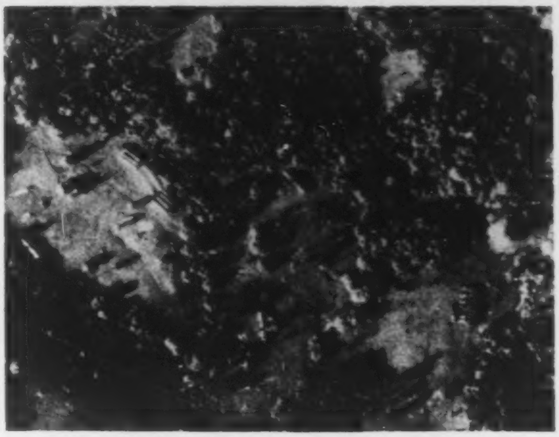

Photo credit: CIA and the National Air and Space Museum, Smithsonian Institution

This U-2 reconnaissance photo provides concrete evidence of missile assembly in Cuba. The infrastructure items shown here are missile transporters and missile ready-tents for fueling and maintenance.

A Test Case of Photointerpretation

The end of the Second World War provided American analysts the opportunity to measure the success of the photoreconnaissance effort to find antiaircraft guns and coastal artillery in the Japanese homeland.[10] This experience seems especially informative from the standpoint of a Conventional Armed Forces in Europe Treaty monitoring regime.

The study found that errors of interpretation (e.g., misclassification of an antiaircraft gun as a coastal artillery gun) occurred in 12 percent or fewer of the cases. Errors of omission occurred at an even lower rate, 5 to 10 percent, in areas where photographic coverage was complete, but went up greatly in areas not subject to exhaustive search. Coast defense guns, lacking the requirement to point upwards, were in some cases concealed to the point of invisibility to "any vertical and most oblique photography." In the case of antiaircraft guns, "strike photography, made while the guns were in use and camouflage removed, revealed the location of many guns which otherwise might not have been detected." Also, "One case of complete concealment of a gun revetment by construction of a movable house built

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[6] Such platforms had just been found near the Chateau du Molay by advancing Allied troops. Jones recognized the roads on the grounds of the chateau as having the same configuration as a previously unexplained set of roads on the foreshore of Peenemünde. These had been used, he deduced, to see whether the V-2's launching vehicle could maneuver in the chateau's driveway.

[7] Jones, op. cit., footnote 2, pp. 549-551.

[8] Robert F. Kennedy, *Thirteen Days* (New York NY: W.W. Norton & Co., 1971), pp. 1-2.

[9] Babington-Smith, op. cit. footnote 3, p. 259.

[10] This section is based on U.S. Strategic Bombing Survey (Pacific), Photographic Intelligence Section, *Evaluation of Photographic Intelligence in the Japanese Homeland, Part Nine: Coast and Anti-Aircraft Artillery* (Washington, DC: U.S. Government Printing Office, 1946).

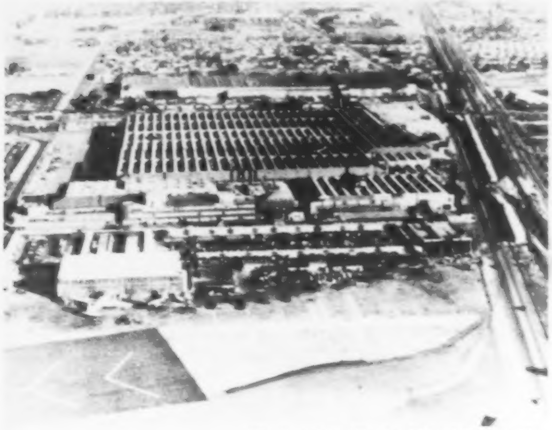

Photo credit: The Lockheed Corporation

Before concerns about Japanese attack led to concealment efforts, an aerial observer would have had little trouble finding and identifying this airplane factory.

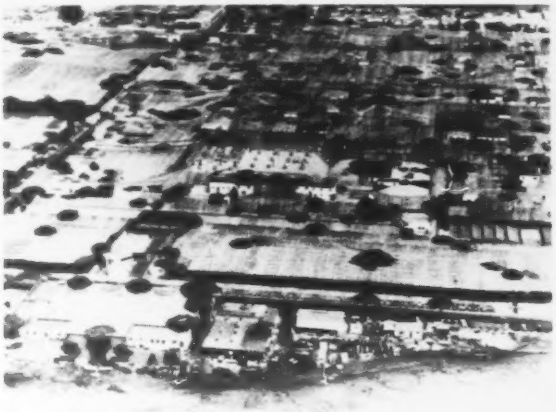

Photo credit: The Lockheed Corporation

Painted buildings and sheets of painted fabric supported by telephone poles make the plant blend in with the surrounding suburbia. A careful photointerpreter might nevertheless see such telltale clues as the road to nowhere (arrow) and the airplane in somebody's yard (foreground).

on rails had not been detected by photographic interpreters." Dummy installations proved very difficult to discriminate from the real thing.

To interpret these results in terms of the lateral range curve paradigm of box 6-B, we ought to keep the 4-mile width and the steep shoulders, but lessen the height of the plateau in recognition of the fact that some targets within the picture will go unnoticed. It is difficult to estimate how far the plateau should be lowered: if we felt that targets in the picture (and thus in a region of complete coverage as cited in the preceding paragraph) have a 20-percent chance of being misclassified or of remaining undetected altogether during a normal amount of photointerpretation, we would lower the top of the curve to the 0.8 level, resulting in a sweep width of 3.2 miles.[11]

Camouflage, Concealment, and Deception

Attempts to frustrate aerial search are almost as old as aerial search itself—very old indeed if one counts ground animals' natural adaptations to avoid predatory birds. Targets can be *camouflaged* (made to appear part of the terrain), or *concealed* (merely hidden from view). Targets can also be left out in the open but made, through *deception*, to appear to be something that they are not.

The Second World War provides numerous instances of imaginative and effective uses of concealment and camouflage. The Lockheed Corporation, for example, provided elaborate camouflage for its Burbank plant, making the buildings appear to be rolling hills in suburbia. Technically, some element of deception was also used, in that artifacts such as houses and roads were included in the camouflage. (See photographs.) Note the use of rooftops painted on the runway and houses painted on the corners of the large hangar in the foreground. Close examination of the camouflaged plant shows certain flaws, such as a road leading to nowhere (arrow) and incongruous airplanes scattered in the left foreground of the picture. Though one need not be a highly trained analyst to identify the false buildings by their lack of shadows, the disguise might have been sufficient to confuse a bombardier.

Soviet military thinkers have placed great emphasis on the techniques of camouflage, concealment, and deception known collectively as *maskirovka* in Soviet military parlance.[12] The photo shows wartime efforts to disguise the Kremlin by painting rooftops on the telltale expanses of Red Square and the interior of the Kremlin. Again, the false buildings' lack of shadows gives them away in the picture (compare, for example, the Lenin Mausoleum—

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[11] Because if we see 80 percent of the targets in a 4-mile-wide swath, we are seeing as many as we would see if we saw 100 percent of the targets in a 3.2- mile-wide swath. The 20 percent figure agrees from the combination of the 12 percent misclassification and 5 to 10 percent omission rates cited in the previous paragraph but cannot be strictly derived from the Second World War experience; aerial search flights would hardly have the advantages cited for strike photography flights, but would be able to penetrate some kinds of camouflage with infrared photography.

[12] See *Camouflage: A Soviet View*, Soviet Military Thought, No. 22, translated and published under the auspices of the U.S. Air Force (Washington, DC: U.S. Government Printing Office, 1989). This is the U.S. Air Force translation of Victor Antonovich Matsulenko's *Operativnaia maskirovka voisk* and *Maskirovka deistvii podrazdelenii sukhotputnykh voisk* by Anatolii Prokofevich Belokon and Sergei Grigorivich Chermashentsev.

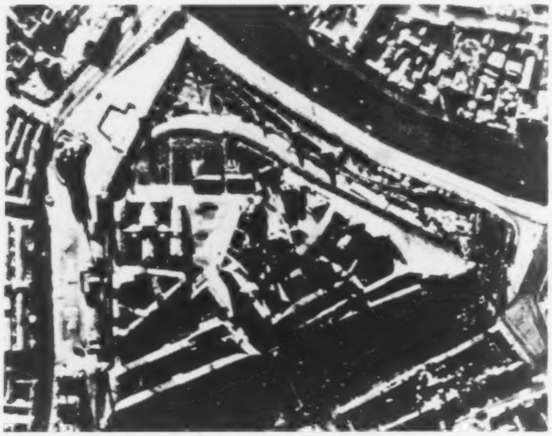


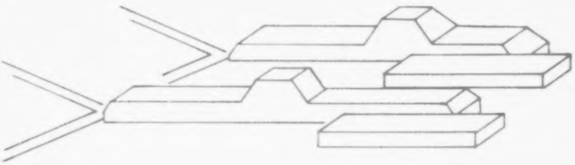
Photo credit: Photograph courtesy of the Department of Defense and the National Air and Space Museum, Smithsonian Institution

This photograph from World War II shows camouflage in the Moscow Kremlin and the adjacent Red Square. The Russians sought to break up the eye-catching open spaces by filling them with dummy buildings. To the trained eye, however, the dummy buildings are given away by their lack of shadows. Compare, for example, the Lenin Mausoleum (at the tip of the shadow cast by the spire of St. Basil's Cathedral) to the "buildings" nearby.

located at the tip of the shadow cast by St. Basil's—to the nearby sham buildings), but they might have helped confuse a bombardier looking for Moscow landmarks amid the havoc of a wartime bombing mission.

Limitations of Deliberate Concealment Measures—Many of the most memorable instances of military deception involve creation of the appearance of military hardware where none is present. Examples include dummy aircraft and tanks to fool image analysts and even false radio traffic to deceive electronic eavesdroppers.[13] Only in the most special of circumstances, however, would introduction of dummy TLIs make sense as a treaty-evasion ploy. One possibility would be the deliberate attempt to make the other side use up a quota of inspections wastefully. Such a ploy would run the risk of violating treaty language regarding interference with verification, or at the very least of showing "bad faith" in compliance matters. Another possibility would be to set up an apparent violation so as to be vindicated when, for example, the seeming SS-20 transporter-erector-launchers (TELs) turn out to be tank trucks; then, after a while, real SS-20 TELs could be deployed with confidence that no further violations would be charged.[14] Still other deception possibilities could be motivated by the desire to test the other side's monitoring capabilities.

Figure B-1—Original Scene



Succeeding figures will show how this scene might appear at various stages of image processing. For clarity, these figures present the scene as if the sensor detected objects' heights, not their brightnesses.

SOURCE: Office of Technology Assessment, 1991.

The mere use of camouflage, much less the invocation of a threatening-sounding term such as "*maskirovka*," does not guarantee success. During the Second World War, German shipyards used carefully manufactured pieces of camouflage to hide work on U-boats. British photointerpreters monitored the progress of the submarines' construction by careful observation of each new camouflage module as it was deployed.[15] Thus, detected camouflage efforts may be worse than useless, calling increased attention to suspect sites.

Image Processing

This section briefly illustrates a few methods of improving images, using cartoon-like images—not actual photographs—in which can be seen individual picture elements ("pixels": these are generated directly by electro-optical devices and could be created from photographic images) and the transformations they undergo. For clarity, these cartoons are made to look somewhat like possible aerial monitoring targets. In most actual pictures, the brightnesses of individual pixels do not correspond in such a simple way to the heights of the objects pictured.

We will examine three sample methods of image processing: contrast enhancement, filtering, and pattern recognition. The first two methods address the problem of retaining the target's image while rejecting unwanted impurities. The third assumes that a good image of the target lies somewhere in the picture but needs to be found.

The original scene is pictured in figure B-1: two submarines are pulling into dock. If digitized, the scene might look—very simplistically—as shown in figure B-2.

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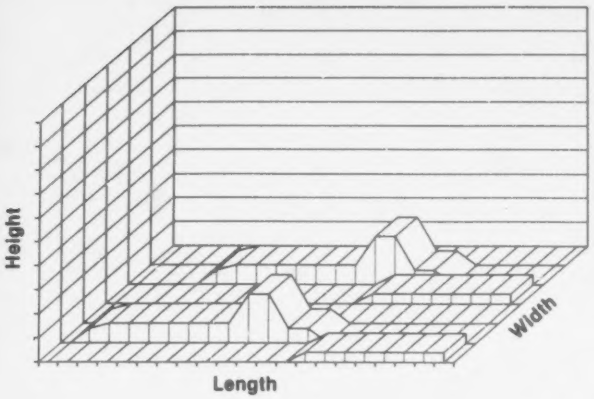
[13] Ibid., pp. 96-98.

[14] In the same vein, the British deployed masses of dummy artillery at El Alamein: the Germans, initially fooled, eventually caught on, whereupon the British replaced the dummies with the real thing. R.V. Jones, *Reflections on Intelligence* (London, England: William Heinemann Ltd., 1989), p. 123.

[15] Babington-Smith, op. cit., footnote 3, p. 113.

[16] This term, from electrical engineering, refers to that which is received but not wanted, in contradistinction to "signal," that which is received and wanted.

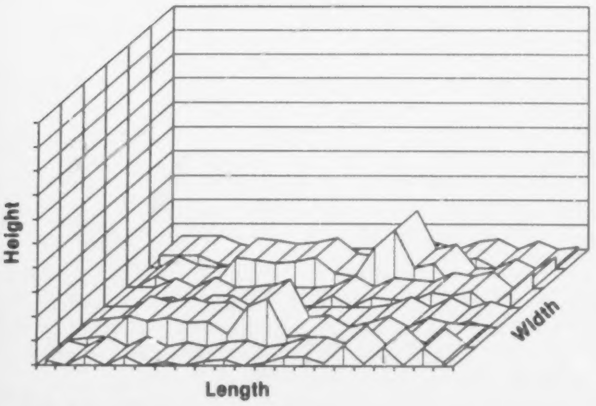
Figure B-2—Digitized Scene



After digitalization, the submarines' images have the boxy look associated with computer graphics.

SOURCE: Office of Technology Assessment, 1991.

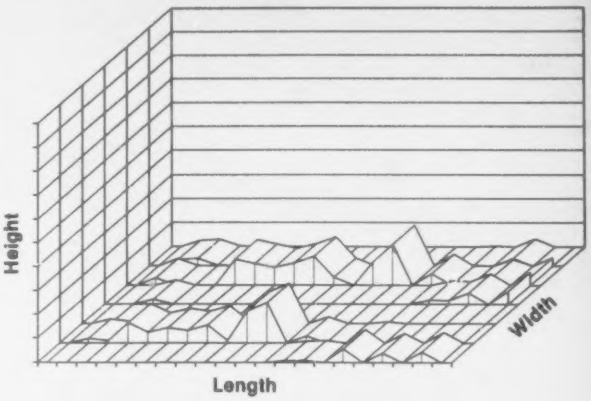
Figure B-3—Digitized Image With "Noise"



The received image will contain not only the digitized scene information, but also—inevitably—some electronic "noise" that distorts the image.

SOURCE: Office of Technology Assessment, 1991.

Figure B-4—Enhanced Contrast Image



One way to recover some of the clarity of the original scene is to enhance the contrast by showing only how much each cell stands out from its neighbors. The human eye uses a similar process to increase image clarity.

SOURCE: Office of Technology Assessment, 1991.

"Noise,"[16] however, inevitably intrudes and degrades the image: the degraded image is shown in figure B-3. Any image-processing method seeks to mitigate the effect of noise by making the target stand out more from the background. However, the method doesn't "know" for sure what is the target and what is the background. It must therefore proceed on the basis of some a priori assumptions about what traits will characterize the target and then process the picture so as to increase the salience of those traits. If the traits have been well-chosen, increasing their salience will increase that of the target.

Contrast Enhancement—Contrast enhancement proceeds from the premise that the target's brightness is likely to differ from that of the background. On this basis, the contrast—differences in brightness between light and dark regions of the picture—is increased in the hope that the targets' outlines will become more apparent.

This method of image enhancement is performed naturally in the human retina, in which cells respond to light not only by emitting a neural output but by reducing that of their neighbors.[17] Such "lateral inhibition" results in an increased perception of contrast because the illuminated cells near a border between light and dark regions of the image receive no inhibition from their unilluminated neighbors on the other side of the border, while the cells in darkness near the border have their already-minimal output further reduced by their neighbors in the illuminated region.

Lateral inhibition can easily be implemented in software. Figure B-4 shows the image after contrast has been increased by dimming each cell in proportion to the brightness of its immediate neighbors and, to a lesser extent, the brightness of its neighbors two cells away. Notice how the images of the submarines and docks, though still "spikey," stand out more from the noise-induced clutter.

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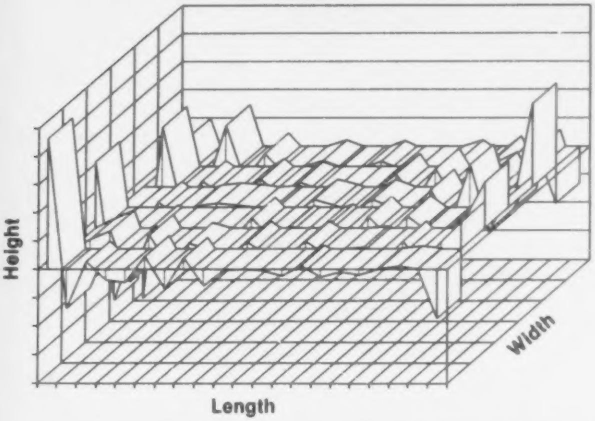
[16] This term, from electrical engineering, refers to that which is received but not wanted, in contradistinction to "signal," that which is received and wanted.

[17] R.L. Gregory, *Eye and Brain*, 2d ed., (New York, NY: World University Library (McGraw-Hill), 1973), p. 76.

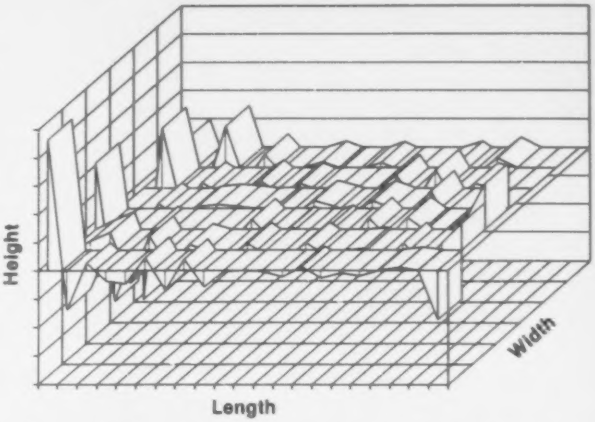
Figure B-5—Spatial Frequency Transform



A more ambitious route to image clarity starts by considering the image as a combination of waves (running lengthwise and widthwise in the picture) and plotting the amplitudes of these waves. The large spike in the left foreground, for example, is the "wave" with a frequency of zero in each direction—its amplitude is the average height of an object in the scene.

SOURCE: Office of Technology Assessment, 1991.

Figure B-6—Filtered Spatial Frequencies



Whereas the submarines and the docks have some regularity to them, the unwanted "noise" in the image varies irregularly from cell to cell. In spatial frequency terms, it therefore has high frequencies, lengthwise and widthwise. To eliminate it, the image processor zeroes out the high frequency cells in the upper right of the spatial frequency plot.

SOURCE: Office of Technology Assessment, 1991.

In a more realistic setting the targets would be more than one pixel wide, and would thus more closely correspond to the concept of contrast enhancement as "edge enhancement."

Spatial Frequency Filtering—Another approach is to assume that the noise is random and thus that the noise level in one pixel will bear no relationship to the noise level in other pixels. Targets, however, can be assumed to occupy more than one pixel, so that the presence of some part of the target in a pixel makes adjacent pixels likely to contain parts of the target as well. Furthermore, the target's brightness can be assumed to fluctuate less than does the noise level. In the received image, therefore (see figure B-3), the signal (the wanted part of what is received) varies less than does the noise (the unwanted part of what is received.)

Fourier transform methods and their close relatives[18] allow the decomposition of signals into their component frequencies.[19] Though most commonly used on signals that are functions of a one-dimensional variable such as time, these methods can be used on two-dimensional images, producing an image in the "transform domain." Figure B-5 shows the Hartley transform of figure B-3 and, like the third picture, represents the received signal-plus-noise version of the scene showing the submarines pulling into dock. Because, as argued above, noise is uncorrelated from cell to cell in the original received image, the majority of the noise content is contained in the upper righthand corner of the picture, whose cells represent the amplitudes of rapidly fluctuating components. By artificially lowering these components' amplitudes to zero, we may hope to eliminate most of the noise. Inverse transformation of figure B-6—the same as figure B-5, but with the high-frequency cells zeroed out—shows (see figure B-7) the submarines and docks clearly, albeit with some distortion and residual noise.

Again, in a more realistic setting, the targets would be larger compared to the pixels than they are in our example. Therefore they would produce an even stronger low-frequency content in the image and the spatial frequency filtering approach would work even better than it does in our simple example. Larger images could contain non-target features, e.g., rolling hills, far larger than targets. Elimination of the images' *low* spatial frequency content would filter out these features.

Pattern Recognition—A problem related to extracting a target's image from superimposed random "noise" is that of extracting a target's image from its surroundings. This problem arises when the imaged region is large compared to the target, leading to the need to search within the image.

The difficulty encountered when attempting to computerize pattern recognition is easy to understand when one reflects on the difficulty of instructing (without recourse

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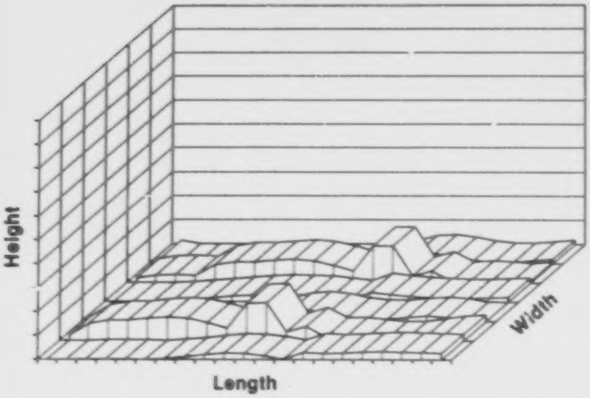
[18] Such as the Bracewell or "Hartley" transform used here. This transform has two advantages in the present application: exact reciprocity of the two domains and the exclusive use of real arithmetic.

[19] If one thinks of the original signal as viewed on an oscilloscope, the Fourier transform shows the same signal as viewed on a harmonic analyzer.

Figure B-7—Inverse Transform of Filtered Transform



With its noise-dominated high-frequency components eliminated, the transformed image is untransformed back from the frequency domain to the original domain. The contours of the submarines and docks are now much more clearly visible than in Figure B-3.

SOURCE: Office of Technology Assessment, 1991.

to pictorial representation) another person to recognize unfamiliar patterns even within a limited domain. Consider, for example, the task of teaching somebody, *through words alone*, to recognize and distinguish dogs of the more than 100 different breeds covered in a typical dog book. Automation of this process is notoriously hard; the general problem of pattern recognition has posed great difficulties over the years despite concerted efforts to solve it. Successes have come only when the problem was somehow restricted to a particular—often very small—domain.

One area of success in pattern recognition has been the guidance of cruise missiles. Terrain Contour Matching (TERCOM) and Digital Scene Matching Area Correlator (DSMAC) systems allow a missile to navigate by comparing passing scenery to stored images. These systems, however, deal with the recognition of whole scenes expected along the route or in the target region, not with the recognition of specified targets amid arbitrary surroundings.

Two-dimensional Fourier transform methods and their relatives can discern the presence of a target's image amid a clutter-filled scene by capitalizing on the fact that although the target could be located anywhere within the scene, its image in the transform domain will always appear in the same place. A simple check of that region of the transform domain will reveal whether or not the target was present in the original image. Further subdivision and retesting of the original image can help narrow down the location of the target, if it is found to be present at all.

The use of a lens to accomplish the Fourier transform simplifies the implementation of the above idea. The transformed scenes are captured on a transparent medium, as is the sample target image. One then shines light through the superimposed transforms of a scene and the sample target onto a screen; a bright blur will appear on the screen if the target appears in the scene.[20]

This method suffers from significant limitations, notably that the image must be known exactly and that although it can be detected regardless of its location within the original scene, it cannot be detected unless it is in the proper orientation. In practice, the latter restriction requires that one test the transform domain for images of the target in all orientations by rotating a test image 360 degrees. Even more problematical is that two images of the same object will differ in far more respects than orientation: scale, illumination, and configuration of movable parts, e.g., turrets and guns, will all vary from image to image.

Change Analysis—The process of inspecting pairs of pictures to see what has changed can be automated if those features that remain unchanged from one picture to the other are—or can be brought to be—superimposed. Features that differ from one picture to the other can then be made to stand out by a viewing device that rapidly alternates from one picture to the other, causing discrepancies to flicker. In the case of halftone (black and white) pictures, copies can be made in complementary colors (e.g. one in green and white and the other in red and white) and the copies superimposed. Unchanged features will then appear in gray, while features that differ from one picture to the other will appear tinted, owing to incomplete color cancellation. In the case of color originals, a similar effect can be obtained by suppressing one of the three primary colors in one picture and another color in the other picture.[21]

Observations

The preceding discussion suggests that while automation can provide considerable assistance with *image processing* (by, as we have seen, increasing contrast or filtering out "noise" in the picture) it has yet to make a comparable contribution to *photointerpretation* as such: the principal contributions to interpretation are really just means of making interesting parts of the image (such as changes) stand out. True automation of interpretation, or even of search, lies in the future. One could say that photointerpretation remains an art, albeit one whose practitioners benefit from some advanced tools.

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[20] See K. Iizuka, *Engineering Optics*, 2d ed. (Berlin, Germany: Springer-Verlag, 1983), pp. 288-290.

[21] Discussion and some good examples of this technique appear in Allen V. Banner, *Overhead Imaging for Verification and Peacekeeping* (Ottawa, Canada: Arms Control and Disarmament Division of External Affairs and International Trade Canada, 1991), pp. 15-19.

Appendix C

AERIAL SEARCH AS A BASIS FOR VERIFICATION DECISIONMAKING

This appendix covers three major points:

1. Evidence gained from aerial search is best used to chose between competing hypotheses, not merely to bolster selected hypotheses. This is especially true of negative evidence.
2. The process of arms control treaty monitoring leads to a situation in which prior subjective judgments and a continuous influx of evidence, much of it negative, need to be blended into a single assessment. This need can be satisfied through the use of Bayesian, as opposed to classical, statistics.
3. Bayesian methods allow calculation of the likely benefit conferred by aerial monitoring, provided—among other things—that the harm inflicted by a violation can be expressed in the same terms, e.g, dollars, as the rest of the calculation. Though difficult, the assignment of a dollar cost to a violation is sensible if we are rationally to allocate money to forestall or detect such violations.

Discussions of unknown Soviet behavior often include statements of the form "We have no evidence of their doing that" on the one hand and "You have no way of knowing everything they're up to" on the other. Many times, each of these statements will be true (see box C-1), and the result a standoff. Yet it can be possible to get more mileage out of negative evidence than is often obtained. The trick is to use it to compare the relative likelihoods of competing hypotheses.

When using aerial surveillance (or indeed any means) to monitor an arms control treaty, the way to use the information it provides is to compare the answers to two questions: 1) "Given that the situation is as I think (or fear) it might be, how likely would I be to see what I am seeing?" and 2) "If the situation were otherwise, how likely would I be to see what I am seeing *anyway*?"[1] Comparison of these likelihoods allows the evidence—even if it is merely the negative evidence provided by a flight that saw nothing—to modify one's assessment of the situation while avoiding the fallacy of "affirming the consequent."[2]

Box C-1—Introducing an Example

The following example will be used in the next several boxes to show various approaches to the problem of sizing an aerial monitoring effort and interpreting its results.

Concern exists that 50 SS-20 transporter-erector-launchers (TELs) might still be somewhere in the Soviet Union.[1] In round figures, the Soviet Union could have about 5 million square miles of ground accessible to off-road-capable TELs: considering their ability to hide in woods, or to spend considerable portions of their time in shelters, the TELs might degrade the ability of the aerial monitoring aircraft to the point that it has a 1-mile effective sweep width. Given the 5-million-square-mile area, a 1-mile sweep width of aerial monitoring aircraft for SS-20s, and a 1,000 mile flight path for each flight, as discussed in ch. 6, each flight has approximately a

$$1 \times 50 \times 1{,}000/5{,}000{,}000 = 0.01$$

or 1 percent chance of detecting some SS-20 or other.[2] Note that this figure is very much different from the flight's

$$1 \times 1 \times 1{,}000/5{,}000{,}000 = 0.0002$$

or .02 percent chance of detecting one SS-20 in particular.

[1] The 50-missile level has been cited as a "ballpark" threshhold of military significance for the SS-20. See *The INF Treaty*, hearings before the Committee on Foreign Relations, United States Senate, 100th Congress, 2nd Session, Part 3, p. 45.

[2] This approximation is valid only because the low density of targets allows us to disregard the effects of random "clumpiness" in their distribution. With a hundred times more targets we would not have a 100-percent chance per flight of finding at least one, because occasions on which we saw one would be balanced out by occasions on which we did not see any.

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[1] Physicians are taught this adage for diagnosticians: "When you hear hoofbeats, don't think of zebras."

[2] In this fallacy, also known as post hoc, ergo propter hoc, the second question stated above is not considered. For example, the argument "If the Russians were to launch a battleship, we would first see them build a large hull; we see a large hull, therefore they will launch a battleship" neglects the possibility that the large hull is being built for some other project, e.g., an aircraft carrier. Those who reason in this way can construe negative evidence almost any way they want to: "If the Russians were building a nuclear airplane they would say nothing about it; they have made no mention of a nuclear airplane, therefore they are working on one."

Box C-2—Probabilistic Approaches

The 1-percent chance (see box C-1) of detecting some SS-20 or other remains unchanged from flight to flight; the treaty-violating TLIs are mobile and can be redeployed between flights, perhaps to regions previously inspected, so that there is no build-up of information about TLI-free regions. The sampling situation is thus one of *sampling with replacement*.[1] Each inspection has a 1-percent chance of finding some launcher or other and a complementary 99-percent chance of not doing so. Taken together, each of a set of inspections must miss all of the targets if the whole set is to turn up no targets; their chance of doing so is 99 percent per inspection, so

$$1 - (1 - .01)^{\text{number of flights}} = \text{chance of finding a violation.}$$

Many violation scenarios of concern are at base breakout scenarios, so one should consider the question of detecting a force during its installation, not afterwards as is normally done. If one assumes constant rates of inspection and violation-installation, one can equate the problem of finding one of 50 launchers as they are installed over a year to that of finding one of 25 launchers that are present the whole time.[2] Deployments and inspections might go on at the rate of one per week, so in the 50 weeks required to deploy the force the inspecting side will have a

$$1 - (1 - .01/2)^{50} = 22 \text{ percent}$$

chance of finding the violation before it is complete.

Simple probability as well as intuition suggests that if each flight has a 1-percent chance of finding a violation, something must be significant about 100 flights. The calculation that

$$1/0.01 = 100,$$

shows that, *on the average*, 100 flights will be needed before the first violation is seen.[3]

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[1] The standard classroom example of sampling with replacement is a situation in which one has an urn containing unknown numbers of blue and red balls. The problem is to determine the proportion in which the two colors are present by repeatedly drawing out a single ball, examining it, throwing it back in, drawing another ball at random, and so on. In the present instance, considering red balls to be violations, the question is how one's confidence that the urn contains no red balls increases with each blue ball examined.

[2] R. Scott Strait of Lawrence Livermore National Laboratory not only demonstrated this surprisingly simple fact but also pointed out its importance in the analysis of the ubiquitous breakout scenario.

[3] The probability distribution underlying this statement is the "geometric distribution."

Though often fruitful even when informally worded, the above approach can be codified mathematically using *Bayesian statistics*. This appendix will show some examples of how such calculations could be done; the search models in ch. 6 readily provide the needed inputs.

Experimental use of Bayesian statistics at the Central Intelligence Agency (including use in problems of photointerpretation) led some to conclude that the method held only limited promise.[3]

Asking the Right Question

Absent any detection of a violation, it is natural for decisionmakers to want to know how the negative evidence accrued up to any given present time affects the probability that an undetected violation exists. The natural tendency of analysts is to cast the answer in terms of the probability that a particular level of violation would have been detected if it existed (see box C- 2): high levels of this probability are taken (given that no violation has been found) as providing high confidence that the particular level has not been exceeded. (See box C-3.) Yet decisionmakers want to know something else, namely the probability that a specified level of violation actually exists, given the evidence collected.

The split can be seen as dividing the analysts and the decisionmakers almost along the classical-v.-Bayesian split in statistics itself. The analysts' view of the problem corresponds closely to that of the classical statistician (who believes in a single—though unknowable—reality and views experimental data as random samples thereof), while the decisionmakers' view more strongly resembles that of a person working within the Bayesian paradigm (who is willing to assign probabilities to various "realities" and views experimental data as fixed "givens"). (See boxes C-4 and C-4a)[4]

A flaw present (though not unavoidable even under the classical paradigm) in many attempts to quantify matters of verification arises from shifting assumptions about the size of a violation. The classical analysis prevalent in the verification literature scales the monitoring effort on the basis that a violation will consist of a militarily significant

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[3] See Walter Laqueur, *A World of Secrets* (New York, NY: Basic Books, 1985): pp. 299-302. Laqueur cites Richards J. Heuer, *Quantitative Approaches to Political Intelligence: The CIA Experience* (Boulder, CO: Westview Press, 1978).

[4] Repeated instances of this sort of split and a renewed emphasis on what might be called a decision-analytic view of statistics have led to a sharp increase in the teaching of Bayesian statistics, once greatly out of favor in academia.

Box C-3—The Classicist's Approach

The classical statistician is used to dealing in high (90 percent, if not 95 percent or 99 percent) confidence levels, and to looking at data and making statements about the state of the world. The statistician will want to assess an inspection scheme by standing in the shoes of somebody examining some large amount of inspection data after the flights have been made; the decisionmaking question is one of interpreting the continuing flow of reports that no treaty-violating missile launcher has been sighted.

More specifically, the classicist seeks to make a statement about the world to which he or she can assign a high probability that it is correct. In the present case, for example, a classicist might like to be able to make the statement that "there is no significant violation" and assign to that statement a 90-percent chance of being correct. The classicist would therefore request that 229 flights be made and, when these flights reported that no violations had been seen, the classicist would make a finding of compliance "at the 90-percent confidence level."[1]

The basis for this statement is the binomial distribution, according to which there is a 10-percent chance that 229 flights would all miss the violation even if it were present in its smallest militarily significant form, given a 1-percent chance per flight of finding it, i.e. that

$$0.9 = 1 - (1 - 0.01)^{229}$$

so that 229 flights would have a 90-percent chance of detecting the militarily signficant violation if it were present.[2] Two hundred and twenty-nine flights which find no violation are required to make the classicist "reject the null hypothesis" that a significant violation exists.

The classicist's statement that he or she has 90-percent confidence in the proposition "no significant violation is present" (given 229 flights which found no violation) might lead a decisionmaker to think that there is a 10-percent chance that a significant violation exists. We may hope that the decisionmaker would ask the classicist to elaborate upon this point. The answer would be that the classicist feels "confidence in the statement at the 90-percent level" because the statement has *at least* a 90-percent chance of being true: it was produced by a process[3] which, if applied repeatedly, would yield correct statements at least 90 percent of the time. When no violation is present the statement will always be made and will always be right: when a violation is present the opposite statement (a finding of noncompliance, certain to be correct because it is backed by evidence from at least one flight) will correctly be made 90 percent of the time[4] and an erroneous finding of compliance will be made 10 percent of the time. Thus the classicist feels that he or she "bats 1,000" in nonviolation situations and "bats 900" in violation situations, and is therefore justified in claiming to bat at least 900 (i.e., make "statements at the 90-percent confidence level") *even without knowing the true mix of violation and non-violation situations*. The classicist might also point out that his or her method will never result in an erroneous finding of non-compliance—findings of non-compliance are only made with hard evidence in hand.

Ninety-five percent confidence could be obtained by flying 298 flights instead of 229. The correct choice of confidence level depends upon the perceived balance between the cost of the flights and the cost of lack of confidence.

The classicist decries the Bayesian approach as "subjective," because, among other reasons, the Bayesian assigns a *probability* to the existence of a militarily threatening treaty-violating missile force. The classicist views such an assignment as incoherent because the force either exists or it doesn't.

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[1] If a violation is found, the classicist will be able to make a finding of noncompliance at the 100-percent confidence level.

[2] More generally,

$$\text{confidence} = 1 - (1 - \text{detection probability})^{\text{inspections}}$$

This easily-derived equation pervades the verification literature, being used, for example, by Dunbar Lockwood in "Verifying START: From Satellites to Suspect Sites," *Arms Control Today*, October 1990, p. 16.

[3] "The classicist is absolutely opposed to the interpretation that the 90 percent refers to the probability that the true popualtion mean lies within the specified interval . . . . A classicist is willing to generate statements with respect to the probability that *the procedure* leads to the generation of correct statements . . . ." (Robert Parsons, *Statistical Analysis: A Decision-Making Approach* (New York, NY: Harper and Row, 1978): p. 329, emphasis in original.)

[4] Note that this figure corresponds to the threshold level of violation. Larger violations would have had a single-flight detection probability of more than 1 percent and thus would have an overall chance of more than 90 percent of being noticed by the 229 flights.

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number of treaty-limited items (TLIs), e.g., 50 missile transporter erector launchers (TELs), and is prepared to return a verdict of "not guilty" (at, say, the 95-percent confidence level) if that effort reveals no TELs. Yet the classicist—like anybody else—is prepared to return a "guilty" verdict if even a single illicit TEL is found. The classical paradigm precludes the direct translation of this finding into an assessment of the probability that a force of 50 missiles is present. In contrast, the Bayesian's method permits such a finding; if a missile or two are seen, the Bayesian will of course announce a violation but will also continue his or her estimation efforts, updating the probabilities that 0, 5, or 50 illicit launchers have been fielded. (See box C-5.)

Box C-4—The Bayesian's Approach

In contrast to the classicist (see box C-3), the Bayesian analyst declines to make flat statements, even at specified levels of confidence, preferring instead to describe the number of missiles present in terms of a probability distribution. He or she views the classicist as ''concealing information''[1] by boiling everything down to a statement regarding the presence or absence of 50 missiles and a figure for a reliability of the process that generated the statement.[2]

The Bayesian addresses the aerial monitoring problem by assigning probabilities to the existence of various numbers of treaty-violating missiles and goes so far as to insist that even before the inspections there must be some a priori or ''prior'' distribution for this number. He or she then interprets the flight data in light of how likely each flight's outcome would be given each number of missiles. Finally, the Bayesian combines the prior probabilites with the probabilities that each flight would turn out as it did, arriving at a ''posterior'' set of probabilities of the existence of the different numbers of treaty-violating missiles.

To implement this approach, the Bayesian needs a single-flight probability of violation-discovery for each number of missiles. Continuing with our example, we will recall the 0.02-percent chance of detection per missile. The Bayesian also needs a prior distribution of different levels of violation. Suppose, for sake of illustration, that somebody supplies a prior distribution to the effect that there is a 5-percent chance that the Russians have a threatening 50 extra missiles, a 70-percent chance that they have a token 5 extra missiles, and a 25-percent chance that they are not cheating at all. This prior, perhaps reflecting a belief that the Soviets are trying to comply but have not quite tracked down all their missiles yet, is expressed by the leftmost two columns of the table, ''Missiles'' and ''Prior.''

Missiles	*Prior*	*Seen*	*Joint*	*Renormalized*
0	25%	100%	25%	31%
5	70%	80%	56%	69%
50	5%	10%	1%	1%
	100%			100%

Now suppose that after 229 flights (not that 229 is a particularly special number of flights for the Bayesian) no violations have been seen. The Bayesian generates the ''Seen'' column by computing the likelihood of this result under each of the three assumptions about how many missiles are actually present. The probability that no missiles would be seen under an assumption that no violations exist is, of course, 100 percent. If 5 violations are present, there is a 0.1-percent chance per flight of seeing at least one and an 80-percent chance of seeing at least one in 229 flights. As arose in the classical case, 229 flights have a 10-percent probability of leaving 50 missiles totally unnoticed. The fourth column shows the joint probabilities of 0, 5, or 50 missiles being in existence *and* resulting in zero sightings after 229 flights. The entries in the fourth column are the products of the respective entries in the second and third columns because of the chain rule of probablity: the probability of events A and B occuring jointly is the probability of A multiplied by the probability of B given that A has occurred. The fourth column thus shows, for each number of missiles, the probability that they are present multiplied by the probability that the flights would have the result that they did (no sightings) with that number of missiles present. These probabilities do not add up to 100 percent because there was not a 100-percent chance that the flights would see no missiles. The fifth column shows the entries of the fourth column renormalized, (that is, the entries are divided by their sum) so as to make their total 100 percent as is required of a probability distribution.[3]

Thus the Bayesian's report on the results of 229 flights shows that the probability of 50 existing undetected launchers has been greatly eroded by the negative evidence of the 229 flights, while the probability that 5 launchers exist undetected has only gone down slightly, because 229 flights are not enough to prove very much about such a small force. The clean bill of health from the 229 flights has somewhat bolstered the case that the other side is not violating the treaty at all.

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[1] Barry Blechman, ''The Impact of Israel's Reprisals on Behavior of the Bordering Arab Nations Directed at Israel,'' *Journal of Conflict Resolution*, vol. XVI, No. 2, June 1972, p. 169.

[2] He or she sees the classicist's objection to the probabilisitic description of a *fait accompli* (albeit an unknown one) as a philosophical quibble: people buy and sell unscratched lottery tickets on the view that the tickets have some probability of winning, when in fact each ticket is foreordained to either win or lose.

[3] This step is needed because we have been considering only certain possible numbers of violating missiles (0, 5, and 50), not all possible numbers (0, 1, 2, 3, . . .). The fact that the original probabilities (of 0, 5, and 50 missiles being present) summed to 100 percent was somewhat artificial in the first place: the originator of such an estimate would ensure for appearances' sake that the sum was 100 percent but would not mean thereby to exclude the possibility of 49 missiles being present. The mathematical operations do not carry this artificiality through, so it has to be reintroduced via renormalization. Additionally, the fourth column, being a joint probability, cannot sum to more that the marginal probability of either of its component events (columns 2 and 3). This will always be less than 100 percent if the evidence collected provides any information at all. Some would object to the blending of the renormalization step (required only because the prior did not consider all possible numbers of missiles) with the division of the joint probability (column 4) by the marginal probability of the evidence. As a practical matter, however, the two steps are done at once by the same division. The marginal probability of the evidence is the denominator, called the ''preposterior,'' in Bayes' Rule. The fifth column is thus the posterior probability of the violation in the first column given the observed evidence—no violations sighted.

The Bayesian's report has the virtue that it answers the question the decisionmaker wants answered: "What is the probability that the other side is violating the treaty?" The Bayesian requires, however, a prior distribution in whose light he or she can consider the findings of the aerial monitoring flights. While the classicist might lodge an objection that the Bayesian is relying on subjectively obtained prior information, the Bayesian can retort that the classicist's 50-missile threshhold and 90-percent confidence level were in themselves subjectively obtained prior standards—the Bayesian approach uses no such standards.

Moreover, the Bayesian could continue, the classicist's standards are inconsistent. The requirement for 229 flights stemmed from a need to determine (with 90-percent confidence) that the Soviets had not fielded a force of 50 illicit missiles. A clean bill of health after these flights will result in a finding (at the 90-percent confidence level) that the Soviets are not in violation; the classicist has retained faith in the 229-flight figure while rejecting the 50-TEL figure on which it was based.[4]

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[4] Arnold Zellner makes a more general version of this point (paraphrasing E.T. Jaynes): "if the null hypothesis is rejected in a non-Bayesian analysis, then so too is the distribution of the test statistic that led to the decision rule for rejection." ("Bayesian Inference," *Time Series and Statistics* (New York, NY: W.W. Norton, 1990), p. 56.)

Box C-4a—The Effect of a Different Prior

As a practical matter, the Bayesian may have difficulty mustering a prior distribution which is acceptable to all concerned.[1] With a somewhat different prior, a somewhat different set of posterior probabilities will emerge from the same flight data. Let us examine the effect of starting with a different prior distribution, perhaps created by a different analyst:

Missiles	*Prior*	*Seen*	*Joint*	*Renormalized*
0	20%	100%	20%	32%
5	50%	80%	40%	63%
50	30%	10%	3%	5%
	100%			100%

Again, the flights have seen no violations, but this analyst's calculations give far more weight to the possibility that a significant violation exists because of his or her use of a different prior. The Bayesian will point out that as more information comes in, the importance of the prior is diluted. Indeed, the right-hand column shows that the evidence of 229 flights that sight no transporter-erector-launchers results in almost the same set of posterior probabilities with the second prior as it did with the first.

The alternative prior distribution shown above is in some sense a greater expression of ignorance than the original prior, in that it accords more nearly equal probability to the three cases. One might be tempted to evade the responsibility of creating a prior by simply assigning equal probability to all the possibilities.

The difficulty with this scheme[2] lies in listing "all the possibilities." One could start with zero missiles and count up, but surely there is some upper limit to the number that the Soviets could deploy, and surely some values near that limit are less likely than some lower ones.

Worse, even if one could list all the possibilities, it is far from clear how one should assign probabilities to them in order to reflect an absence of preconceived notions. For example, assume that incontrovertible evidence (perhaps related to production capacity) shows that there can be no more than 99 illegitimate missiles deployed. An analyst could then perform calculations like those shown above, according a prior probability of 1 percent to each of the 100 possible numbers of missiles (0, 1, 2, 3, . . . 99) and defending this prior on the grounds that its uniformity reflects the absence of any preconceived notion as to the number of missiles. However, the assigned 1-percent probability that zero missiles have been deployed reflects a 99-percent certainty that the Soviets are cheating in some degree, hardly an absence of preconceived notions.

In any case, to seek parsimony of assumption through the use of an ignorant prior is to underestimate the amount of information available—the size of a likely treaty-violating force is bounded from above by economic considerations and from below by military effectiveness.

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[1] A difficulty mentioned by D.V. Lindley in "Statistical Inference," *Time Series and Statistics*, op. cit., box C-4, p. 291).

[2] Termed "notorious" by Koopman. (Bernard Osgood Koopman *Search and Screening*, (New York, NY: Pergamon, 1980), p. 286.)

Aerial Monitoring as a Basis for Confidence

We should think of aerial monitoring in a broader sense than that of simply catching Soviet violations of arms control treaties. (Box C-6 sets the stage for the coming examples.) Aerial monitoring might extend beyond treaty monitoring to the more general function of providing assurance that the other side was not mobilizing for war. Even with regard to treaty monitoring the function of providing confidence that the treaty is not being violated would be at least as important as the function of giving warning that it had been.

To perform this compliance-monitoring function, however, the aerial monitoring regime must bolster confidence in a negative—the proposition that the Soviet Union is not violating a treaty or mobilizing for war. As experienced lawyers and debaters are well aware, to "prove a negative" can be difficult or impossible.

Treatment of Negative Evidence

As part of the Intermediate Range Nuclear Forces (INF) Treaty verification process, the Soviets gave the United States a data package regarding the SS-20 intermediate range ballistic missile. Asked if the package was accurate, Admiral William J. Crowe responded, "We do not have the evidence or the conviction to say that it is inaccurate."[5] This "Scotch verdict" is informative only if one has some idea of how likely the United States would be to possess information disconfirming the package if the package were in fact inaccurate.

Asked about many possible scenarios, intelligence analysts will respond, "We have no evidence of such activity." These analysts can hardly be faulted for declining to speculate in the absence of evidence, but one must exercise care in interpreting their silence because it raises the question, "Would you have evidence if they were actually doing it?" This question gets very close to the Bayesian's question, "How likely would I be to see what I am seeing if the activity were going on?"

Much of the utility of the Bayesian formulation lies in the fact that it can incorporate negative evidence as well as positive evidence. A flight that produces no evidence of treaty violation is viewed by the Bayesian as supporting the case for treaty compliance *insofar as* a violation, were one to exist, might have been noticed by the flight.[6] This measured use of negative evidence differs from the naive conclusion that "absence of evidence is evidence of absence" and from the traditional conclusion that a lack of evidence proves nothing either way.

Discussion of treaty monitoring begs the question of what action would be undertaken in response to the discovery of a violation, so such an assessment must hinge upon the action that the United States would take upon finding an anomaly or violation as the result of a flight, and upon the difference in impact upon the United States of finding an anomaly or violation sooner rather than later.

This report will not attempt to prescribe any such actions, but we will consider one—the deployment of countervailing intercontinental ballistic missiles (ICBMs)—as an example of how the costs of reacting to a violation affect the monitoring process itself.

Harm Inflicted by Treaty Violation

It is difficult to assess, let alone quantify, the harm inflicted by a treaty violation. (Boxes C-7 and C-8 show two possible approaches.) Much depends upon the treaty, and the violation, but even so one might credibly follow any of several lines of reasoning and attach costs varying from close to zero to close to infinity to the harm inflicted by a given treaty violation. Why then even try to estimate the cost imposed by an arms control treaty violation? In particular, the idea of assigning a dollar cost to the harm caused by deployment of treaty-violating TLIs may seem bizarre. However, we budget treaty-monitoring resources in dollars. Therefore, we need some estimate of what these dollars buy us in terms of harm avoided, just as if we were instead budgeting for the construction of a retaliatory force or a system of active defenses.[7]

The Expected Value of Information

For the purposes of illustration, we will proceed with an analysis based on the example in box C-8, of $500 million per undiscovered (and hence uncountered) missile and $200 million per discovered (and countered) missile. Different assumptions will produce different results.

Let us compare the cost of performing the aerial monitoring inspections v. the cost of not doing so. The reader is again reminded that this calculation is an

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[5] *NATO Defense and the INF Treaty*, Hearings Before the Committee on Armed Services, U.S. Senate 100th Cong., 2d sess., part 1, p. 121. Asked to clarify the point regarding "conviction," the Admiral replied "I do not believe that the evidence supports it in what we have."

[6] More pessimistically, a flight that produces no evidence of a treaty violation can be viewed as evidence that the collection equipment isn't working, insofar as one thinks that violations are present. The methodology presented in this chapter could be expanded to characterize formally this updating of a prior probability that the equipment doesn't work. A closely related difficulty is that one might be using the equipment to look for the wrong thing, as may have been the case in the anti-Scud campaign of the Gulf War, in which the search for Scud TELs overlooked the more prevalent "mobile erector launchers" expediently produced in Iraq.

[7] Classical statistics would require the even more problematical imputation of value to *confidence* in missiles *not being present*. While one might reasonably think that the presence of 50 illegitimate missiles is approximately twice as deleterious as the presence of 25 (or the 50-percent probability of the presence of 100), there is little intuitive appeal to the idea that the absence of 100 missiles is twice as nice as the absence of 50.

Box C-5--The Bayesian's Report After a Sighting

The table shows what the Bayesian would report if one transporter-erector-launcher (TEL) were sighted in the course of 229 flights, given the same prior distribution for the number of illicit launchers deployed as was used in box C-4.

Missiles	*Prior*	*Seen*	*Joint*	*Renormalized*
0	25%	0%	0.00	0%
5	70%	18%	0.13	92%
50	5%	23%	0.01	8%
	100%			100%

The Bayesian again generates the "Seen" column by computing the likelihood of this result under each of the three assumptions about how many missiles are actually present. The probability that one missile would be seen under an assumption that no violations exist is, of course, 0 percent: sighting a TEL would be impossible if there weren't any,[1] so no chance remains that the Soviets have fielded no illicit TELs. If 5 were fielded, 229 flights would have an 18-percent chance of seeing exactly one; if 50 were fielded, 229 flights would have a 23-percent chance of seeing exactly one.[2] Combined with the respective prior probabilities for the deployment of these numbers of missiles, these probabilities result in a 92-percent chance that 5 TELs are deployed and only an 8-percent chance that a significant violation featuring 50 illicit TELs is underway.

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[1] Though *thinking* that one had sighted a TEL would not be. A more complete analysis would take into account the possibility of "false alarms" in which TELs are reported where none exist.

[2] It may seem paradoxical that a tenfold increase in the deployment causes such a modest increase in the probability of seeing exactly one TEL. The reason is that although 1 TEL is a lot to find if 5 are deployed, it is a small number to find if 50 are deployed—the sighting of exactly 1 TEL is in fact mild evidence *against* the proposition that 50 are deployed, because one would expect the searches to reveal more than 1 TEL in that case.

Box C-6—Introducing Another Example

The following example describes our treatment of cost considerations. We will maintain our focus on a violation that would clearly be of some harm to the United States, namely a violation of a ballistic missile launcher limit. The following assumptions, chosen purely for simplicity and plausibility, will govern our consideration of the problem: Aerial monitoring flights detect illegitimate missile launchers as described in box C-5: each flight exerts an effective sweep width of one mile over a 1,000 mile path in a 5-million-square-mile-region of the Soviet Union. The actual search portion of a flight consumes 2 hours of flying time, with another hour spent in takeoff, landing, gaining altitude, and other nonsearch portions of the flight. The flights cost $50,000 apiece all told. This estimate is based on a 6-hour Washington-Los Angeles flight breaking even at about 200 passengers paying about $300 apiece. Flying the aerial monitoring aircraft will cost roughly $10,000 per hour for 3 hours. The other $20,000 is the cost of the reconnaissance functions themselves, including interpretation performed afterwards. To check this estimate, we may note other indicators of the cost per flying hour of various types of aircraft. The manufacturer of a twin-engine turboprop aircraft cites its $2,000/hour overall expense as a compelling factor in its favor.[1] Aerobureau, a private firm, proposes to lease a Lockheed Electra (the civilian equivalent of a P-3 Orion), equipped with "side-looking airborne radar, infrared and low light television sensors," to TV news networks for a $250,000 6-month lease and a $2,000/day operating fee covering the aircraft and flight crew.[2] The owner/operator of a USAAF B-29 restored to flying condition reported a $3,000/hour cost of operation with a volunteer crew.[3] A B-1 wing flying four sorties per plane per month expends $242 million in operating costs per year, suggesting a cost per sortie of almost $100,000.[4]

Costs of different aerial photography systems are often usefully compared in terms of dollars per square mile.[5] Assuming that the 1-mile sweep width cited above stems from a 20 percent effective photographic search of a 5-mile swath (not an unreasonable assumption: see box 6-A), this search costs $10 per square mile.

Some number of treaty-violating launchers may be deployed. The U.S. side's set of prior probabilities for the number of illegitimate missiles deployed is the same as it was in box C-5.

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[1] John King, "Airborne Remote Sensing for Open Skies" *Open Skies* (Toronto: York University Center for International and Strategic Studies, 1990), p. 33.

[2] Aviation Week and Space Technology, August 20, 1990, p. 13.

[3] Personal communication.

[4] Testimony of General John T. Chain Jr., . *Threat Assessment; Military Strategy; and Operational Requirements*, hearings before the Committee on Armed Services, U.S. Senate, Mar. 7, 1990: page 898.

[5] See, for example, Amrom H. Katz, "Let Aircraft Make Earth-resource Surveys," *Astronautics and Aeronautics*, June 1969, reprinted under the same title as RAND Paper P-3753, available from The RAND Corp., Santa Monica, CA. Katz's costs per square mile are considerably lower than than the figure presented here not only because of the greater value of the dollar in 1969 but also because of the less-demanding resolution requirements of the earth-resource survey mission.

Box C-7—Harm Inflicted by Treaty Violation: Valuation According to Extra Potential Damage

One could also place a dollar cost on the harm done by a violation according to the destruction the violating weapons would inflict were they used against the United States. If the extra loss of life and limb—always difficult to cast in dollar terms—were costed at the rates paid in injury liability cases, the casualties from one nuclear missile could soar far into the billions. On the other hand, densely populated areas are presumably already targeted by the missiles and other strategic nuclear delivery vehicles allowed under arms control treaties: treaty-violating missiles will be applied[1] to marginal targets left uncovered by the legitimate force.

The damage done to inanimate objects is somewhat less difficult to cast in dollar terms. One estimate of this amount comes to 36 times the cost (procurement and lifetime operation, or about $200 million for the Peacekeeper) of the weapons themselves,[2] so that a violating missile imposes a cost of about $7 billion on the United States. The factor of 36 could be assailed on the grounds that although it assumes complete obliteration of the United States, its imputation of worth is restricted to "asset value," and as such includes neither loss of life and limb, or loss of items and sites of cultural value. Thus the factor of 36, obtained by assuming that the entire heavy Soviet intercontinental ballistic missile (ICBM) force would destroy the entire United States, may be assailed as too high on the grounds that it is an average value, not a marginal value.

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[1] If not directly, then through the legitimate missiles they displace from the higher-priority targets.

[2] Gregory Canavan and Edward Teller (in "Strategic Defense in the 1990," *Nature*, Apr. 19, 1990) derive this estimate for the SS-18, noting that "overestimates of the effects of nuclear explosions may have caused many readers to guess a higher figure." They take the SS-18 to cost as much as its U.S. counterpart, the Peacekeeper, and they assume that the entire force of 308 SS-18s could destroy the entire United States. The value thus destroyed is derived from U.S. gross national product and economists' usual ratio (about 4:1) of total assets to production. An upper limit on the total worth of American people, assets, and cultural items that could possibly be destroyed in a war would be the total insured value underwritten by all insurers, property, casualty, and life. People, vehicles, and land aside, insurers cover about $12 trillion in assets: inclusion of vehicles and allowance for the existence of various forms of uninsured property would raise this figure to $15 trillion or more.

Though we may be startled by the seeming lowness of the 36:1 ratio of the missile's cost to its destructiveness, we should recall that conventional bombing notoriously destroys less than it costs.

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illustrative one based on the assumptions listed above. Moreover, the real issue is the effect of aerial monitoring upon monitoring as a whole; the correct comparison would really be all other monitoring with versus without aerial monitoring added. Without any aerial monitoring flights, the cost is the harm done by the presence of any illegitimate missiles, expressed in dollar terms as explained above. Using a prior distribution for the probabilities that various numbers (including zero) of illegitimate launchers are present, we may find the expected value (translated into millions of dollars) of the harm done by the missiles: $3 billion.

Missiles	*Prior*	*Cost*	*E(cost)*
0	25%	0	0
5	70%	$ 2,500	$1,750
50	5%	$25,000	$1,250
			$3,000

Aerial monitoring flights would have some chance of detecting the violations committed in the 5-missile and 50-missile cases. Two hundred flights, each effectively sweeping a 1-mile swath 1,000 miles long, might each have a 0.02 *percent* chance (as we have seen in ch. 6) of finding one launcher: this probability can be multiplied by 5 or 50 to get the single-flight probability of finding a violation, and the chance of *not* finding the violation then raised to the 200th power to obtain the probability of *not* finding a violation during the 200 flights. We may thus compute the probability of finding the violations. Recalling that we assume that a violation costs $200 million per launcher to counter and $500 million per launcher if it remains hidden, recalling that the 200 flights themselves cost a total of $10 million, and using our prior probability distribution for the chances that each level of violation (including none at all) is present, we may find the expected value of the cost of each violation

Missiles	*Prior*	*Find violation*	*E(cost)*
0	25%	0%	5
5	70%	18%	$1,564
50	5%	87%	$ 601
			$2,170

For example, the 5-launcher violation has an estimated 70 percent probability of being present in the first place and a probability of

$$1 - (1 - 5 \times 0.0002)^{200} = 0.18$$

of being detected by some one of the 200 flights or other if it is present, so that the total expected cost of the 5-missile case (including the cost of performing the inspections, even if they find nothing), is

$$0.7 \times ((5 \times (0.18 \times 200 + 0.82 \times 500)) + 10) = 1564$$ [8]

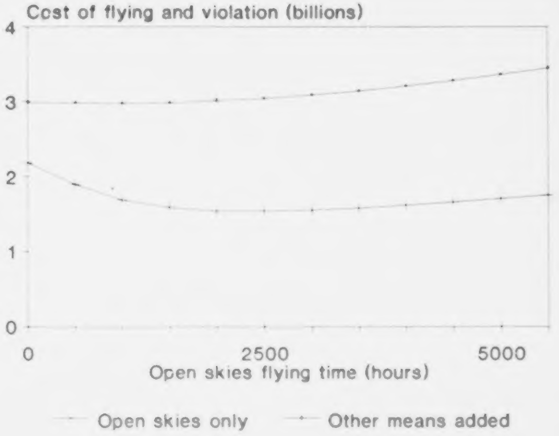
or $1.564 billion: $200 million per missile if the violation is detected and $500 million otherwise. The expected cost of the situation as a whole is $2.18 billion if inspections are undertaken—less than the cost without the inspections. Therefore the inspections are the preferable course of action under these assumptions, though by a small enough margin that other reasonable assumptions could

Box C-8—Harm Inflicted by Treaty Violation: Procurement Cost of Counteracting a Violation

Another position would evaluate the violation at the cost of the violating weapons, or of their U.S. equivalents, on the grounds that the U.S. response to a violation would be to build similar weapons to maintain parity. However, the U.S. preference for arms control over arms racing suggests that the United States feels that having weapons aimed at it has a cost greater than the cost of aiming our own weapons back. Very roughly, then, this middle view might attribute to an uncountered treaty-violating missile a one-time cost of $500 million to the United States.

A violation which was found and countered by the deployment of a U.S. missile can be more readily evaluated at the cost to counter, roughly $200 billion for a U.S. intercontinental ballistic missile (ICBM). Use of other legs of the triad to counter a violation would cost more: ICBMs offer the least cost per alert warhead.

Figure C-1—Notional Costs of Inspections and Violations (detected and undetected violations)



The expected sum of the cost of the inspections and the imputed costs of violations represents the total cost to the Nation. An amount of flying can be chosen to minimize this total. The upper curve depicts a situation, described in the text, in which only Open Skies flights can detect a violation. The lower curve shows the contribution of some other means of detection that, albeit at a cost, greatly increases the probability that a violation will be detected.

SOURCE: Office of Technology Assessment, 1991.

lead to the opposite conclusion.[8] One unstated assumption with which serious issue might be taken is that finding one or more illegitimate launchers somehow brings about discovery of the whole violation. This is one effect which brings down the cost of the 50-missile case. (Another is the low prior probability assigned to that case.) The assumption is not totally unreasonable, in that discovery of a violation would shift the whole treaty-monitoring effort into high gear and probably bring other intelligence collection assets to bear. The expense of using those extra assets should properly be charged against the cost of countering a treaty-violating missile, perhaps increasing the $200-million figure we have been using. **Another unstated assumption has been that the aerial monitoring flights afford the only opportunity for catching the violations. In the real world, this assumption is unwarranted and the analysis should be redone using correct overall costs of monitoring and correct overall probabilities of catching violations.**

Savings Expected From Aerial Monitoring

Referring to the computations of the previous sections, we may attempt to assess the worth of the 200 aerial monitoring flights by finding how much money we can expect them to save us. Given all of our assumptions, including the prior distribution of the probabilties of the various violations, we find an expected cost of $3 billion without the flights and one of $2.17 billion with them so that the flights save us $830 million net, including the costs of the flights.

More generally, we may find the worth of various numbers of aerial monitoring flights by finding their expected net cost and comparing it to the expected $3 billion cost of not having any flights at all, always keeping in mind that the result depends upon all of our assumptions, including our *a priori* estimates of the likelihood of various levels of violation and our dollar-cost characterizations of the harm done by countered and uncountered violations.

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[8] Certainly the precision of some of our assumptions does not justify the retention of four decimal places in the result, as has been done for the sake of clarity in illustrating the structure of the calculations.

NATO'S PROPOSED BASIC ELEMENTS FOR OPEN SKIES

Open Skies: Basic Elements

The following text outlines the basic elements of NATO's Open Skies negotiating position. These elements were agreed to by the North Atlantic Council Meeting in Ministerial Session at NATO Headquarters, Brussels, on 14th and 15th December 1989.

I. INTRODUCTION

1. On 12th May 1989, President Bush proposed the creation of a so-called "Open Skies" regime, in which the participants would voluntarily open their airspace on a reciprocal basis, permitting the overflight of their territory in order to strengthen confidence and transparency with respect to their military activities.

This proposal expanded on a concept that had already been proposed during the 1950s but had failed to reach fruition because of the unfavourable international political climate prevailing at the time.

Today, this new initiative has been made in a very different context as openness becomes a central theme of East-West relations and the past few years have been marked by important advances in the areas of confidence-building and arms control.

2. The provisions for notification and observation of military activities specified in the Helsinki Final Act were strengthened and made obligatory by the Stockholm Document concluded by the CDE [Conference on Disarmament in Europe] in 1986.

With respect to arms control, in 1987, the INF [Intermediate-Range Nuclear Forces] Treaty, apart from its immediate goals, represented a very important precedent because of the extent of its verification provisions.

All this leads one to expect today that even more spectacular advances will be achieved in the near future. In particular, a two-pronged effort is under way in Vienna: on the one hand, to deepen the measures for confidence-building and transparency among the 35 countries of the CSCE [Conference on Security and Cooperation in Europe], and the other, to reach an unprecedented agreement between the countries of the Atlantic alliance and the Warsaw Treaty Organization on the elimination of large numbers of conventional arms.

Furthermore, one awaits important developments in other sectors of disarmament such as chemical weapons and the Soviet-American strategic arms negotiations.

3. All of these agreements will naturally require their own verification regimes, often of a highly intrusive nature. Moreover, the specific provisions of each verification treaty will be supplemented by the habitual means by which countries verify compliance with agreements (National Technical Means).

It seen is useful, however, particularly in the prevailing context of improved East-West relations, to reflect on other ways of creating a broadly favourable context for confidence-building and disarmament efforts.

In this context, the Open Skies concept has a very special value. The willingness of a country to be overflown is, in itself, a highly significant political act in that it demonstrates its availability to openness; aerial inspection also represents a particularly effective means of verification, along with the general transparency in military activities discussed above.

This double characteristic of an Open Skies regime would make it a valuable complement to current East-West endeavors, mainly in the context of the Vienna negotiations but also in relation to the other disarmament efforts (START [Strategic Arms Reduction Talks], chemical weapons).

It would seem desirable to focus now on the European region, while also including the entire territories of the Soviet Union, the United States, and Canada. Accordingly, we will be ready to consider at an appropriate time the wish of any other European country to participate in the Open Skies regime. This element could be complementary to their efforts at confidence-building and conventional arms control and would conform to the objectives of those negotiations.

4. To this end, the Open Skies regime should be based on the following guidelines:

- the commitment of the parties to greater transparency through aerial overflights of their entire national territory, in principle without other limitations than those imposed by flight safety or rules of international law.
- the possibility for the participants to carry out such observation flights on a national basis or jointly with their allies.
- the commitment of all parties to conduct and to receive such observation flights on the basis of national quotas.
- the establishment of agreed procedures designed to ensure both transparency and flight safety.
- the possibility for the parties to employ the result of such overflights to improve openness and transparency of military activities as well as ensuring compliance with current or future arms control measures.

II. PURPOSE

The basic purpose of Open Skies is to encourage reciprocal openness on the part of the participating states and to allow the observation of military activities and installations on their territories, thus enhancing confidence and security. Open Skies can serve these ends as a complement both to National Technical Means of data collection and to information exchange and verification arrangements established by current and future arms control agreements.

III. PARTICIPATION AND SCOPE

Participation in Open Skies is initially open to all members of the Atlantic Alliance and the Warsaw Treaty Organization. All territories of the participants in North America and Asia, as well as in Europe, will be included.

IV. QUOTAS

1. Open Skies "accounting" will be based on quotas which limit the number of overflights. These quotas will be derived from the geographic size of the participating countries. The duration of flights can also be limited in relation to geographic size. For larger countries, the quota should permit several flights a month over their territory. All of the parties will be entitled to participate in such observation flights on a national basis, either individually or jointly in co-operation with their allies.

2. Effective implementation of a quota system requires agreement that a country will not undertake flights over the territory of any other country belonging to the same alliance.

3. Quota totals for participating states should be established in such a manner that there is a rough correspondence between totals for NATO and the Warsaw Treaty Organization and, within that total, for the USSR and the North American members of NATO.

4. Every participant, regardless of size, would be obligated to accept a quota of at least one overflight per quarter.

5. Smaller nations, that is, those subject to the minimum quota, may group themselves into one unit for the purposes of hosting Open Skies overflights and jointly accept the quota that would apply to the total land mass of the larger unit.

V. AIRCRAFT

The country or countries conducting an observation flight would use unarmed, fixed-wing civilian or military aircraft capable of carrying host country observers.

VI. SENSORS

A wide variety of sensors would be allowed, with one significant limitation—devices used for the collection and recording of signals intelligence would be prohibited. A list of prohibited categories and types of sensors will be agreed among the participating states which will be updated every year.

VII. TECHNICAL CO-OPERATION AMONG ALLIES

Multilateral or bilateral arrangements concerning the sharing of aircraft or sensors, as well as the conduct of joint overflights, will be possible among members of the same alliance.

VIII. MISSION OPERATION

1. Aircraft will begin observation flights from agreed, pre-designated points of entry and terminate at pre-designated points of exit; such entry and exit points for each participating state will be designated by that state and listed in an annex to the agreement.

2. The host country will make available the kind of support equipment, servicing and facilities normally provided to commercial air carriers. Provision will be made for refueling stops during the flight.

3. An observing state will provide 16 hours notification of arrival at a point of entry. However, if the point of entry is on a coast or at a border and no territory of the receiving state will be overflown prior to arrival at the point of entry, this pre-arrival period could be abbreviated.

4. The crew of the observation aircraft shall file a flight plan within six hours of its arrival at the point of entry.

5. After arrival and the filing of a flight plan, a 24 hour pre-flight period will begin. This period is to allow time to determine that there are no flight safety problems associated with the planned route and to provide necessary servicing for the aircraft. During this pre-flight period the aircraft will also be subject to intrusive but non-destructive inspection for prohibited sensors and recorders.

6. Prior to the flight, host-country monitors will be able to board the observatory aircraft. During the flight they would ensure that the aircraft is operated in accordance with the flight plan and would monitor operation of the sensors. There would be no restrictions on the movement of the monitors within the aircraft during the flight.

7. The flight will be from the agreed point of entry to an agreed point of exit, where the host country observers would depart the aircraft. The points of entry and exit could be the same. Loitering over a single location will not be permitted. Aircraft will not be limited to commercial air corridors. Observation aircraft may in principle only be prohibited from flying through airspace that is publicly announced as closed to other aircraft for valid air safety reasons. Such reasons would include specific hazards posing extreme danger to the aircraft and its occupants. Each country will make arrangements to ensure that public announcements of such hazardous airspace are widely and promptly disseminated; each

country will produce for an annex to the agreement a list of where these public announcements can be found. The minimum altitudes for such flights may vary depending on air safety considerations. The extent of ground control over aircraft will be determined in advance by agreement among the parties on compatible rules such as those recognized by ICAO [International Civil Aviation Organization]. In the application of these considerations and procedures, the presumption shall be on behalf of encouraging the greatest degree of openness consistent with air safety.

8. The operation of the Open Skies regime will be without prejudice to states not participating in it.

IX. MISSION RESULTS

Members of the same alliance will determine among themselves how information acquired through Open Skies is to be shared. Each party may decide how it wishes to use this information.

X. TRANSITS

A transit flight over a participating state on the way to the participating state over which an observation flight is to be conducted shall not be counted against the quota of the transitted state, provided the transit flight is conducted exclusively within civilian flight corridors.

XI. TYPE OF AGREEMENT

The Open Skies regime will be established through a multilateral treaty among the parties.

XII. OPEN SKIES CONSULTATIVE BODY

To promote the objectives and implementation of the Open Skies regime, the participating states will establish a body to resolve questions of compliance with the terms of the treaty and to agree upon such measures as may be necessary to improve the effectiveness of the regime.

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